REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
9 May 1995

3. REPORT TYPE AND DATES COVERED
Final Report 1991-1995 Dissertation

4. TITLE AND SUBTITLE
Derivation and Application of Measures of Conformance to Army Operations Doctrine

5. FUNDING NUMBERS

6. AUTHOR(S)
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KR95-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Student Detachment
Strom Thurmond Soldier Center
Ft. Jackson, South Carolina

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
Prepared in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Industrial and Systems Engineering, Georgia Tech, 1995

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; Distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*) A blueprint for analyzing doctrine with respect to its relationship to combat victory was developed and then used to develop 14 measures of doctrinal conformance to four of the Tenets of Army Operations doctrine-Agility, Depth, Initiative, and Synchronization. All of the measures developed related to the two tenets of Agility and Synchronization while a basis for other measures related to Depth and Initiative was built. The measures use observable battlefield data taken from force-on-force battles fought at the National Training Center. Using computer graphical representations of the actual battles, experts were asked to test the validity of the measures. Six measures were strongly supported by the test including Organizational Agility, Physical Agility, Fire Support BOS, MCMS BOS, Weapons Usage, and Invulnerability. Six other measures were indicated as valid but not fully supported. The measures, along with their ties to doctrine, should be valuable as diagnostic tools for the commanders and staffs of combat units both during and after exercises, wargames and simulations. They should also aid those who develop doctrine to evaluate the value of proposed doctrinal changes.

14. SUBJECT TERMS
Doctrine, measurement, synchronization, Agility, Depth, Initiative, hierarchy, measures of conformance

15. NUMBER OF PAGES
491

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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Derivation and Application of Measures of Conformance to Army Operations Doctrine

A THESIS
Presented to
The Academic Faculty

by

Jack M. Kloeber Jr.

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in Industrial and Systems Engineering

Georgia Institute of Technology
May 9, 1995

Acknowledgements

During the past 41 months, I have relied upon the knowledge and support of many people. I would like to start by recognizing my family for its patience, support, words of encouragement, and love. My daughters, Mary and Sophia, and my son Jack have kept my spirits high and have given me energy when I needed it most. My wonderful wife, Elena, has taken so much of the burden of running a family upon herself to free up my time and effort for this dissertation. To even start this endeavor would have been impossible without her.

I would like to thank Rick Cleaveland for his very comprehensive and helpful technical editing of Chapters One and Three. I am sure the dissertation is better and I have improved my writing because of his help.

I must acknowledge the two dozen Army officers at the Georgia Institute of Technology and at the Air Force Institute of Technology that assisted me in the experimental portion of the dissertation. Each of them contributed at least two hours and gave me insight into the problems associated with mea-

suring and evaluating doctrine. Three fellow students were also my sounding boards either for the military soundness of proposed measures, the mathematical support for them, or both. I would like to thank PhD students Lieutenant Colonel Hoa Generazio, Major Dave Frye, and Ileana Castillo.

Dr. Alex Kurlik helped me through the beginning phases of analyzing the doctrinal hierarchy and opened up the world of human decision-making to me. Dr. David Goldsman, as my chief statistics advisor, along with Dr. Christos Alexopoulos, helped me select and use the proper statistical techniques. I thank them for their availability and willingness to help.

I spent many hours on the phone with US Army analysts, historians, and modelers. None was more helpful than Major Jude Fernan from the TRADOC and Analysis Command in Monterey, California. As my link to past research accomplished at the Naval Postgraduate School, he also personally ensured that I received the computer and database support required while in California.

Dr. Callahan was an integral member of my committee. He was invaluable in his historical perspective, knowledge of the origins of US Army doctrine, and had a vast network of analytical and military contacts. I spent many hours with him discussing the beginning and the future of doctrinal

development, weapons system definitions, and why this dissertation was so long.

My advisor, Dr. Donovan Young, was the perfect example of a PhD advisor. He encouraged discussion and yet was painfully truthful with his evaluations. He cut my 'pontificating' down to a minimum, after several tries, and taught me much about editing. More than anything else, Dr. Young kept me focused on the goal of doing important, solid research. I thank him for his patience, insight, and creativity.

Finally I would like to thank my entire thesis committee, including Drs. Young, Callahan, Hackman, Mulaik, and Tovey, for adjusting schedules, reading drafts, offering very useful advice, and actively taking part in this effort.

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Glossary

agility To manifest the ability to act or react quickly with as much force as possible. A tenet of Army Operations Doctrine.

air defense BOS All measures designed to nullify or reduce the effectiveness of attack by hostile aircraft or missiles after they are airborne [FM 25-101 90].

anticipation The act of avoiding surprise as operations unfold; mental or physical preparations due to predictions of future events to increase the likelihood of a positive outcome.

applicability One of the principles of variable selection. A state of a variable of being relevant and significant to the cause or purpose of the representation.

area of influence The geographical area of a battlefield that can be significantly affected by the weapon systems under the control of a single commander.

area of operations A geographical area assigned by a higher commander to a unit; physically defined by lateral and rear boundaries.

aspect of doctrine A major component or class of concepts used in the theory of warfare. Aspects of doctrine are used to both organize the concepts behind doctrine and to convey an intended meaning to the user of doctrine. An example of a set of aspects of doctrine is the set of five tenets of Army Operations doctrine.

audacity A measure related to the tenet of *initiative* from the Army Operations doctrine. It measures the frequency and magnitude of the *boldness* of a unit's actions.

battle command The art of battle decision making, leading, and motivating soldiers and their organizations into action to accomplish missions. Includes anticipation, optimization, visualization, and prioritization.

battle command BOS The operating system that coordinates, plans, and controls the other six battlefield operating systems. The battle command BOS is responsible for prioritizing effort and allocating resources [FM 25-101 90].

battle damage assessment The process of determining the essential tactical reconstitution requirements for an attrited unit.

battlefield operating systems (BOS) The major functions occurring on the battlefield and performed by the force to successfully execute operations. The seven systems are:

- Intelligence
- Maneuver
- Fire Support
- Mobility, Countermobility, Survivability
- Air Defense
- Logistics
- Battle Command

[FM 25-101 90]

battle space Intellectual components and a physical volume determined by the maximum capabilities of a unit to acquire and engage the enemy. Includes areas beyond the area of operations (AO). *Battle space*

varies over time according to how the commander positions his assets [FM 100-5 93].

branch A contingency plan for changing the disposition, orientation, or direction of movement of the force [FM 100-5 93].

campaign A series of related, joint major operations designed to achieve one or more strategic objectives within an area of responsibility [FM 100-5 93].

center of gravity The hub of combat power and movement, upon which everything depends. It is that characteristic, capability, or location from which a force derives its freedom of action, physical strength, or the will to fight [FM 100-5 93].

combat power unit An artificial of measurement for the total amount of destructive power available; based upon the characteristics of the weapon system being analyzed and the type of ammunition being used. (See OLI)

combat service support The essential functions, activities, and tasks necessary to sustain all elements of operating forces in an area of operations. At the tactical level of war, it includes, but is not limited to, that

support rendered by service support troops in operational and tactical aspects of supply, personnel, maintenance, transportation, health services, and other services required by aviation and ground combat troops to permit those units to accomplish their missions [FM 100-5 93].

combined arms A behavioral measure of the tenet of *synchronization* from the Army Operations doctrine. Coordinated application of several *battlefield operating systems* during the battle. Indicates the balance of the use of the various BOS by use of the variance of the normalized *weapons usage* scores.

commander's intent A concise expression of the purpose of an operation, a description of the desired end state, and how the posture of that end state facilitates transition to future operations. [FM 100-5 93]

comprehensibility One of the principles of variable selection. A characteristic of a variable indicating its intuitiveness or its ease of being described with explicit, unambiguous language. A certain minimum of domain knowledge is assumed.

control the terms of battle To dictate to the enemy when, where, and

how the battle will fought. Behavior that is related to the tenet of *initiative* from the Army Operations Doctrine. Measures the degree to which a unit is forced to change the timing critical events due to the unforeseen actions of the opposing force. Control of the terms of battle is separable into:

- Control of Tempo
- Control of the location of the battle(s)
- Control of type of battle (i.e., the posture)

control A measure of behavior related to the tenet of *synchronization* from the Army Operations doctrine. Measures the degree to which the combat power is purposefully arranged with respect to both time and space.

culmination point The point in time and space when the attacker's combat power no longer exceeds that of the defender, or when the defender no longer has the capability to defend successfully [FM 100-5 93].

data Values that can be manipulated, stored, retrieved, or used in computation.

defensive overlap A measure that is used in computing the measure of

doctrinal positioning. A quantity (see Section 3.5) intended to measure the success of a unit in locating assets outside killing zones of the opposing force.

deployment The relocation of forces to desired areas of operations. The movement of forces within areas of operations.

depth A tenet of Army Operations doctrine. A characteristic of operations that allows the force to secure advantages in later engagements, protect the current close fight, and defeat the enemy more rapidly by denying freedom of action and disrupting or destroying the coherence and tempo of its operations. [FM 100-5 93]

doctrinal positioning A behavioral measure of the tenet of *synchronization* from the Army Operations Doctrine. Indicates how closely doctrine is adhered to when placing friendly combat power in relation to enemy assets and enemy combat power.

doctrine Fundamental principles by which military forces guide their actions in support of national objectives. It is both descriptive and prescriptive in nature. The most current manual states, "doctrine is au-

thoritative but requires judgement in application." [FM 100-5 93]

end state A set of required conditions which, when achieved, attains the aims set for the operation [FM 100-5 93].

engagement A small, tactical conflict, usually between opposing maneuver forces [FM 100-5 93].

execution The actions that occur during a battle. Included in execution are the technical aspects of movement, target acquisition, firing, battle drills, preparation of fighting positions, and staff work.

fidelity One of the criteria of models, along with *generalizability and parsimony.* The degree of closeness of a model's predictions or results to reality.

fire support BOS The collective and coordinated use of target acquisition data, indirect fire weapons, armed aircraft (less attack helicopters), and other lethal (e.g., naval gunfire) and nonlethal means against ground targets in support of maneuver force operations. [FM 25-101 90]

generalizability One of the criteria of models, along with *fidelity, and parsimony.* Robustness; not too restricted to specific terrain, unit type,

weather or other common battlefield variables.

information The assignment of meaning or worth to data values. Information implies a use or purpose which may be specific to the user. Examples of information are:

- The assignment of 'number of tanks left' to the data value '25' in the results field of an After Action Report.
- The assignment of 'Departure Time' to the data value '0630' in the LD field of an Operations Report.

initiative An aspect of Army Operations doctrine along with *agility, synchronization, depth, and versatility.* The behavior of setting or changing the terms of battle, including tempo, geographical location, and posture (i.e., offense or defense).

intelligence BOS The collection of functions that generate knowledge of the enemy, weather, and geographical features required by a commander in planning and conducting combat operations [FM 25-101 90].

interdiction Actions to divert, disrupt, delay, or destroy enemy's surface military potential before it can affect friendly forces [FM 100-5 93].

joint task force A force composed of assigned or attached elements of two or more services which is constituted by appropriate authority for a specific or limited purpose or missions of short duration [FM 100-5 93].

lines of communication (LOC) All the routes (land, water, and air) that connect an operating military force with a base of operations and along which supplier and military forces move. [FM 100-5 93]

logistics BOS The support and assistance provided to sustain forces, in the fields of logistics, personnel, and health services [FM 25-101 90].

major operation The coordinated actions of large forces in a single phase of a campaign. A major operation could contain a number of battles or could be a single critical battle.

maneuver BOS The employment of forces on the battlefield through movement and direct fires to achieve a position of advantage with respect to enemy ground forces in order to accomplish the mission.[FM 25-101 90]

maneuver The manifestation of *mobility.* A measure related to the tenet of *agility* from Army Operations Doctrine. It is a measure of behavior that reflects how quickly combat power is actually moved on the battlefield.

It is represented by a ratio of the weighted sum of combat power for each type of weapon system and the total amount of combat power available to the unit. The weight for the individual weapon systems is the average speed throughout the battle divided by the maximum speed for that type of weapon system.

measurability One of the principles of variable selection. Each of the variables used in a model should be judged on its:

- Orthogonality
- Measurability
- Applicability
- Comprehensibility
- Parsimony

measurable A quantity computable from raw data which yields a meaningful score (nominal, ordinal, interval, or ratio) related to a measure. Preferred attributes of a measurable are the same as those of variable selection. An example of a measurable is *spatial control* developed for the measure of *control.*

measure Indicator of an aspect of doctrinal behavior. Usually quantifiable and relevant to only one aspect of doctrine. Can be a function of one or more other measures. An example of a measure is *control. Control* is an indicator of the level of *synchronization* used during a battle. It is a function of *spatial and temporal control.*

mental agility A measure of the *agility* tenet of Army Operations doctrine. Intended to measure how quickly a commander makes decisions about the course of action the unit will take.

military model An abstraction of reality, the elements of which are chosen for (a) an investigative purpose or (b) a resource management purpose. An abstraction to assist in making decisions. [MORS 84] Also used for diagnostics and evaluations.

mobility The ability to move combat power and units quickly on the battlefield. This characteristic is classified as a capability. See *maneuver.*

mobility, countermobility, and survivability BOS The capability of the force permitting freedom of movement relative to the enemy while retaining the ability to fulfill its primary mission. Includes those ac-

tions that the force takes to remain viable and functional by protection from the effects of enemy weapons systems and natural occurrences. [FM 100-5 93]

model A simplified representation of the entity it imitates or simulates. [MORS 84]

movement control The planning, routing, scheduling, and control of personnel and freight movements over *lines of communication.* [FM 100-5 93]

offensive A measure related to the initiative aspect of Army Operations doctrine. To be ready to go on the offensive whenever the opportunity arises. Offensive action forces the enemy to react rather than act. An offensive force sets the terms of battle.

operational art The employment of military forces to attain strategic goals through the design, organization, and execution of battles and *engagements* into *campaigns* and *major operations.* In war it determines when, where, and for what purpose major forces will fight over time [FM 100-5 93].

operational lethality index (OLI) An index indicating amount of com-

bat power inherent in a weapon system. It was developed by Trevor Dupuy in the 1980's for predicting battle outcomes using the combat potential of weapon systems rather than pure numbers of soldiers or weapons [Dupuy 85].

operations in depth The totality of the commanders operations against the enemy – composed of deep, close, and rear operations which are usually conducted simultaneously in a manner that appears to the enemy as one continuous operation against him.

organizational agility A behavior of the staff of a military unit which is related to the tenet of *agility* from the Army Operations doctrine. Intended to measure how quickly an organization acts and reacts to changing missions and changing battlefield conditions.

orthogonality A state of separateness and distinctness between two variables in a model. Indicates a lack of a cause-and-effect relationship between the variables. Conceptual independence.

overwhelming combat power The ability to bring together, in combination, sufficient force to ensure success and deny the enemy any chance

of escape or effective retaliation.

parsimony One of the criteria for evaluating models. It calls for a model with the simplest combination of variables and the smallest number of variables, while still maintaining a required degree of **fidelity**.

physical agility A measure of the *agility* tenet of Army Operations doctrine. Intended to measure how quickly combat power is moved around the battlefield. See *mobility* and *maneuver*.

planning A measure related to the *depth* tenet of Army Operations doctrine. Indicates the detail and the scope of the organizational effort that occurs by the commander and staff before the execution.

publish To issue, usually in written form, an order to a subordinate unit that explains, in detail, required actions for the current or coming battle.

reaction time A behavioral measure of the *agility* tenet of Army Operations doctrine. The average amount of time used in the decision cycle of a unit. The decision cycle time includes:

- Phase 1 – Time from occurrence to acquisition of the information.

- Phase 2 – Time from acquisition to transformation of information into intelligence
- Phase 3 – Time from receipt of intelligence to issuance of orders
- Phase 4 – Time from issuance of orders

reconstitution At the operational and tactical levels, it comprises extraordinary actions that commanders plan and implement to restore units to a desired level of combat effectiveness commensurate with mission requirements and available resources [FM 100-5 93].

reserves A measure related to the depth aspect of Army Operations. It is a measure that indicates the amount of support contributed by the reserve force(s). The support can be in the area of security, successful reinforcement of a committed unit, or replacing a committed unit that needs reconstitution.

risk-taking A measure related to the *initiative* tenet of Army Operations doctrine. Taking a risk is beginning a task whose rewards or negative consequences is uncertain. Although every decision maker takes a risk in implementing any decision, risk-taking per se occurs when there is an

explicit recognition that the rewards and the probability of achieving them outweigh the negative consequences and their associated likelihood of occurrence.

spatial control A measurable, developed for the measure *control* that yields a score of the level of spatial organization exerted over the forces on the battlefield. The score is an average of the spatial control (entropy) computed for each of time snapshots of the distribution of combat power. The spatial control for one time period is the negative of the sum of the individual entropy calculations for each 100m X 100m grid section.

spatial depth A measure related to the *depth* tenet of Army Operations doctrine. It is a measure of the intensity of operations occurring in the rear, in the deep battle, and on the flanks.

strategy The art and science of employing the armed forces and other elements of national power during peace, conflict, and war to secure national objectives.

surprise A measure of behavior related to the tenet of *initiative* from Army

Operations Doctrine. It is the degree to which a force behaves contrary to the behavior prescribed by its doctrine. This particular definition is used because surprise normally means to do the unexpected. However, an opposing force expects the other force to act according to its doctrine. Therefore, an opposing force's expectations can be taken out of the calculations and replaced with doctrine, thus making the measurement independent of the enemy's thoughts, ideas, or actions.

synchronization Focusing resources and activities in time and space to produce maximum relative combat power at the decisive point [FM 100-5 93]. A tenet of Army Operations Doctrine. Synchronization is a behavior, a series of actions.

tempo A measure related to the tenet of *initiative* from the Army Operations Doctrine. The rate of military action. All military operations alternate between action and pauses as opposing forces battle one another and friction to mount, and then execute, operations at the time and place of their choosing.

temporal control A measure developed for the component *control*, that yields a score of the level of temporal organization exerted over the

forces on the battlefield. The score is a combat-power-weighted average over all grids and time periods of the temporal control (negative entropy; see Section 3.5) computed for each grid for each time period.

temporal depth A measure related to the *depth* tenet of Army Operations doctrine. It is a measure of the degree to which future operations were planned and coordinated, as well as how far in the future enemy and friendly actions were being considered.

tenets A basic truth held by an organization. The fundamental tenets of Army Operations Doctrine describe the characteristics of successful operations [FM 100-5 93].

testability One of the principles of modeling. The ability of a model to be tested through availability of data, accurate measurement of the input, consistent use of the model, and measurable comparisons of the actual results to predictions.

training The instruction of personnel to individually and collectively increase their capacity to perform specific military functions and tasks [FM 25-101 90].

weapons usage A measure related to the *synchronization* tenet of Army Operations doctrine. It measures the level of the actual firing and use of available combat power.

Summary

A blueprint was developed for analyzing doctrine with respect to its relationship to combat victory. Using a hierarchical approach, the blueprint was used to develop 14 measures of conformance to four of the Tenets of Army Operations doctrine – Agility, Initiative, Depth, and Synchronization. U.S. Army experts tested the measures by reviewing training battles from the National Training Center (NTC) and comparing their evaluations against the measures' calculated values. Using the Wilcoxin Signed Rank Sum test, six measures were strongly supported by the experts. They are: Organizational Agility, Physical Agility, Fire Support BOS, Mobility, Countermobility, and Survivability BOS (Defense), Weapons Usage, and Invulnerability.

There was indication of validity for six other measures although the results from the test did not show significant support. They are: Temporal Control, Spatial Control, Maneuver BOS, Air Defense BOS, and Combat Power Projection. Mental Agility, and Mobility, Countermobility, and Survivability BOS (Offense) could not be tested.

All of the measures use observable battlefield data in their models. The measures should be valuable as diagnostic tools for the commanders and staffs

of combat units both during and after exercises, simulations, and wargames. They should also aid those who develop doctrine to evaluate the value of proposed doctrinal changes.

Computer programs for computing all the measures from the NTC databases are given. Also presented are weapon characteristics and final combat power values for each U.S. and Soviet weapon in the database. Dupuy's Operational Lethality Index (OLI) formulas were used to produce the scores.

CHAPTER 1

Description of the Problem

The research reported in the thesis develops and evaluates specific objective measures of conformance to U.S. Army doctrine. The measures can be calculated from data already maintained for battle training exercises or from similar data for simulations or, eventually, battle information systems in actual warfare. They are intended to be diagnostic, so that they can be useful in decision support systems in battle or exercises or simulations, giving commanders immediate insight comparing their actions to doctrine. (They are not measures of effectiveness, which abound; rather, they are diagnostic measures of behavior in the conduct of battle, which are currently unavailable.)

The measures are developed and illustrated in Chapter Three. In Chapter Four they are evaluated against experts' subjective estimates of the elements of doctrine that they purport to indicate. In Chapter Five they are proposed for use in various information systems.

Sections 1.1 and 1.2 below introduce combat decision-making and doctrine. Section 1.3 relates decision-making and doctrine to the recent Gulf War so as to familiarize the reader with how doctrine is used and to show

how commanders' actions currently are evaluated and to introduce how the data needed to compute measures of conformance are already collected and maintained. Finally Section 1.5 provides a formal problem statement for this research and guides the reader through the remainder of the dissertation.

1.1 Introduction

In battle the goal is victory. The U.S. Army spends billions of dollars annually on training, technology, and maintenance to enable our soldiers to attain victory. To assist in accomplishing the Army mission of "...being capable of decisive victory" [West 94], the Army leadership has developed doctrine. Doctrine is a set of guidelines and principles that have been developed over time which are thought to be valuable for guiding a unit to victory.

Doctrine is used by the commander to help choose proper courses of action at various levels of command, before and during combat. Doctrine helps the commander systematically consider the many factors that affect the outcome of the battle.

A model of doctrine's current role in assisting combat decision making is shown in Figure 1.1. The figure portrays the elements that influence the commander's decision of determining the proper course of action. The decision is affected by *perceptions* of:

- Environment
- Mission
- Doctrine
- Enemy actions

- Resources available to both opponents.

Several alternative courses of action are usually offered by a commander's staff and the commander decides upon a final course of action. Once orders (written or verbal) reflecting the decision have been issued, the following elements will have an effect on the outcome of the battle:

- Resources available
- Friendly actions
- Enemy actions
- Posture
- Environment

The outcome of the battle has its own effects including a new force ratio (ratio of friendly to enemy combat power), a changed perception of the enemy's actions, and a changed disposition of both enemy and friendly forces. A change in any of these key elements may cause the commander to change his course of action.

For doctrinal training and analysis purposes, it would be useful to be able to measure and control many of the inputs that affect the outcome of the battle. The Army has developed excellent methods for measuring the level of execution and controlling resources. At our national training sites, even the environment can be somewhat controlled. Although it would be difficult to objectively measure the commander's choice of a course of action, it should be possible to measure the results of that choice. If resources and

Combat Decision Making Model

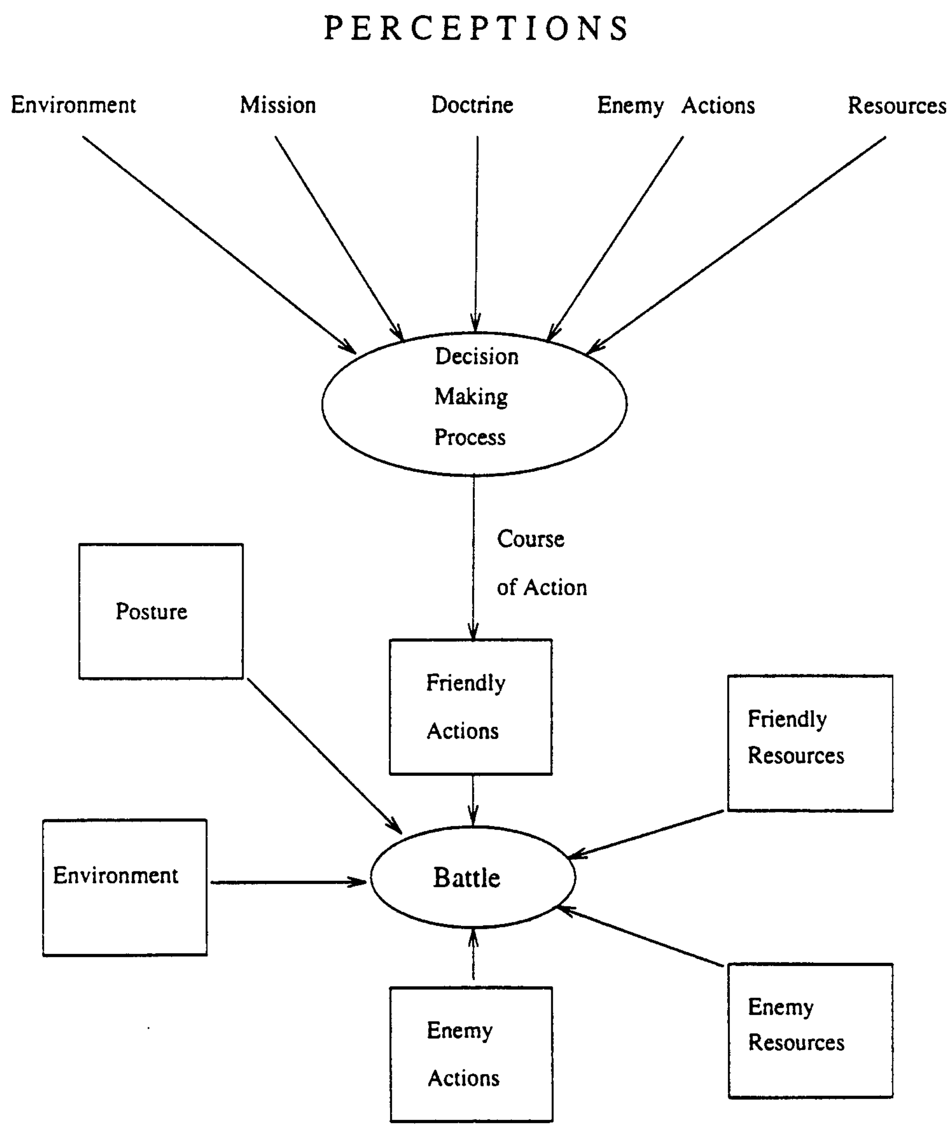


Figure 1.1: Battlefield Decision Making Process Diagram

the environment are controlled and the level execution is measured, friendly force actions can be interpreted as the manifestation of the commander's decision. Once we can relate these actions to what doctrine prescribes, a conformance to doctrine measure will be attainable. The problem becomes one of finding or developing methods in which the closeness of actions to doctrinal principles can be determined. The US Army has no method to accomplish such measurment.

"The U.S. Army is doctrine-based" [FM 100-5 93] and approval of its doctrine is accomplished at the Department of the Army level. Army units are expected to adhere to approved doctrine. Army leaders are expected to use doctrinal principles to guide them in choosing their courses of action. Both the quality of doctrine and the commander's adherence to doctrine are important factors affecting the outcome of a battle. If doctrine is ill conceived but adhered to by the commander, the likelihood of victory is diminished. If doctrine is sound but ignored or violated by the commander, the likelihood of victory should also be diminished.

Ease of evaluation has not been a major concern in the development of doctrine. Doctrine is designed to instruct, motivate, clarify, and inspire. The structure of doctrine was not designed to be orthogonal, independent, or even necessarily suitable for numerical analysis. This author will propose a method for analyzing current US Army doctrine and, subsequently, a method for synthesizing developed measures that indicate conformance to specific areas of doctrine. The analysis will be a top-down approach until objective measurables from available data are achieved. Using a bottom-up approach, an aggregation methodology will be used to indicate the level of conformance to broader principles of doctrine. The result will be a structure of current U.S.

Army doctrine which supports quantitative measures of a unit's conformance to doctrine. Such measures are necessary if understanding and control of the outcome of battle is desired.

Doctrinal conformance measures are not intended to be goals for which all commanders should strive. Instead they are presented as a diagnostic tool for analyzing past battles. They can be used as a training device, indicating where specific training is needed if doctrinal conformance in a specified area is deficient.

Conformance measures may also be used for evaluating past, current, and new doctrines. The differences in battle outcomes of high-conformance battles can be considered effects of differences between doctrines. Doctrine is not static, but dynamic, as evidenced by the four complete revisions of FM 100-5 *Operations* in the period 1976-1993. Because doctrine contains guidelines for winning in battle, when the nature of battle changes, doctrine is also affected. The writers of doctrine need a tool that can be used for consistent doctrinal improvement.

Note: For the reader who is unfamiliar with combat models or with the type of data that is now available from training centers, a hypothetical example battle is explained along with the data that would be obtained from it. See the last section in Chapter Three entitled "Example."

1.2 Doctrine

Conformance cannot be rationally discussed until doctrine is adequately defined. In this section, doctrine will be defined, past doctrine examined, and current doctrine presented.

1.2.1 Doctrine Defined

To win wars, armies fight battles. Which major battles must be fought is dictated by the National Military Strategy, Strategic and Operational doctrine, and the regional or global situation. How the battles are fought is prescribed by tactical doctrine and decided by the tactical commander.

A useful definition for doctrine is "a principle or body of principles presented for acceptance or belief, as by a religious, political, scientific, or philosophic group; dogma" [Am Heritage 85]. Militarily, a more specific definition is offered by Gabel [Gabel 92]: "Doctrine is the collective body of thinking and writing that describes how a military organization expects to fight. It suggests how the assets available should be orchestrated and employed to attain the desired ends. At the tactical level, doctrine seeks to assure that ... battles are victories by describing how the arms and services should be organized effectively on the battlefield." Gabel believes that military doctrine is both descriptive and prescriptive since it *describes how* and *tells how* the services *should* be organized.

Finally, Major Herbert [Leavenworth Paper #16] presents doctrine as, "authoritative fundamental principles by which military forces guide their actions." A slight modification of Herbert's definition will serve as the operative definition of doctrine for this research: **Authoritative fundamental principles, at times either descriptive or prescriptive, by which military forces guide their actions.**

Doctrine is descriptive in that the principles are developed from success and failures from past Missions and exercises. These principles describe actions taken that most often result in success. They are prescriptive in

that they offer guidelines to be followed by leaders while planning for and conducting battle.

1.2.2 Background

Theory of War

Warfare has intrigued theorists for centuries. Alexander the Great had his way of planning the strategy and conducting the battle. The Roman generals of 200 BC to 300 AD felt that their legions were the answer to correct and efficient warfare. After the Mongol Hordes proved them wrong, hundreds of years followed during which strategists attempted to develop the most useful and most general principles of warfare. Clausewitz [Clausewitz 32], in his classic work *On War* included eight chapters covering everything from general strategy to specific defensive and offensive operations. The chapter on general strategy, Chapter Three, included topics became the first principles of combat (see Chapter Two).

Much of Clausewitz' writing is descriptive in nature. He looked at past wars and tried to generalize the common principles behind the victories. Most of the topics could also be interpreted as prescriptive theory. For example, one may read Clausewitz as a developer of a theory which demands that a commander maximize boldness, demonstrate perseverance in his actions, achieve superiority in numbers and utilize the element of surprise to the extent possible. These are the elements of Clausewitz's theory of winning in battle. Strategists, theorists, wargamers, and practicing soldiers have tried their hands at developing a very general yet applicable structure of the theory of winning in battle. Such attempts have often been tied to

specific technological breakthroughs which eventually became meaningless as the breakthroughs became classic and later antiquated [vanCreveld 91]. Technology *is* a major driver in changing the nature of battle. Technological breakthroughs such as gunpowder, rifles, and self-propelled armored vehicles have forced doctrine to change as the face of battle has changed. U.S. Army doctrine typically lags behind technological development, due to the descriptive nature of doctrine and the natural inertia of a large organization [Callahan 71]. Political change can also affect the nature of battle. The advent of the Cold War with its polarization of political beliefs, drastically changed conditions surrounding the battlefield. Equally significant were the end of the Cold War and the dissolution of the U.S. Army's major threat: Soviet and Eastern Block countries' ground forces.

In the past 80 years, warfare has undergone significant transformations as seen by the type of warfare engaged in during the major conflicts:

- World War I – trench warfare and widespread use of chemicals
- World War II – Blitzkrieg and air war, emphasis on armor, introduction of atomic weapons
- Korean War/Vietnam War – Insurgency, small-unit and dismounted operations, and massive conventional bombing
- Israeli Warfare – Large formations and anti-armor emphasis
- Iraqi War – Massive air strikes and huge maneuvers coupled with high technology intelligence
- Conflicts in Yugoslavia and Somalia – Multi-national forces and peace-keeping, peacemaking, and counter-terrorism missions.

Early U.S. Doctrine

The doctrine of the U.S. Army has also changed dramatically over the years as evidenced most profoundly by the changes in the Field Manual FM 100-5 *Operations.* The current version of this manual is hardly recognizable compared to the published doctrine used to train units to fight as recently as 20 years ago. Not only has Army doctrine changed but also doctrine's role in training and fighting. The U.S. Army was still publishing World War II doctrine as late as 1964 [Leavenworth Paper #16]. World War II doctrine was fast-paced compared to World War I, mainly because the tank had become the predominant weapon system. The main anti-armor weapon was another tank. The doctrine consisted of linear formations, direct fire assaults using artillery supporting fires, and less use of, and dependency on, terrain. In 1943, there was more emphasis on massing forces than on maneuvering them, compared to present day doctrine. The flank and rear of the enemy were considered secondary or tertiary alternatives. Maneuver was slow and difficult to coordinate due to problems in communications and logistics operations that struggled to support the operation. As the generals [Leavenworth Paper #16] found during the Korean War, there was little value to the published doctrine except for its laundry list of important aspects of warfare that should be kept in mind. Lessons learned during the Korean war were not included in doctrinal manuals until the early 1970s. Published doctrine during the 1970s was never altered to reflect tactics that were found to be successful in Vietnam. Until General William DePuy took command of the Training and Doctrine Command in 1975, the doctrine was entirely *descriptive* in nature. In 1976, the Field Manual became more of a

prescriptive manual. DePuy's Active Defense doctrine received poor reviews and limited acceptance by the military community [Gabel 92] [FM 100-5 76]. In 1982, General Starry signed the Operations Manual that proposed Airland Battle Doctrine [FM 100-5 82]. The Active Defense had been replaced along with many of DePuy's ideas. However, the concept of Airland Battle had actually been introduced by DePuy in the 1976 version. The emphasis on prescriptive doctrine was kept in the 1982 version and strongly supported throughout the Training and Doctrine Command (TRADOC). Because of its generalizability and acceptance by the decision makers in the Army, the Airland Battle doctrine has had few revisions since 1982. Until June of 1993, the four Tenets of Airland Battle doctrine were:

- Agility
- Initiative
- Depth
- Synchronization

1.2.3 Current U.S. Doctrine

The reader has been led through the combat decision-making process. The problem of measuring the closeness of friendly actions to the principles of doctrine led to the definition of doctrine, the early history of the use of doctrine, and US Army's early approach to doctrine. A variety of organizations of doctrinal concepts will now be presented to the reader, followed by the conclusion that the four tenets of Army Operations are the logical choice for the analysis performed in Chapter Three. A series of manuals, schools, and

training exercises have been designed to teach Army Operations doctrine to today's soldiers. Although there are scores of manuals published for teaching doctrine of specific areas of combat (e.g., Armor, Infantry, or Field Artillery), the keystone manual for Army Operations doctrine is the recently updated FM 100-5 *Operations.*

Army Operations Tenets

Airland Battle Doctrine [FM 100-5 86] lists four basic tenets that are claimed to be the keys to success for the Army on today's battlefield. The four tenets – Agility, Initiative, Depth, and Synchronization – have not been quantified sufficiently to be measurable as indicators of conformance to doctrine in analysis of combat operations, combat simulations, or training exercises [Dryer 91]. The 1993 version of FM 100-5 [FM 100-5 93] includes the four tenets from Airland Battle Doctrine but also adds a fifth. The five tenets of Army Operations, as defined by the current FM 100-5 *Operations*, are paraphrased here:

- **Agility** is the ability of friendly forces to act faster than the enemy. It is a prerequisite for seizing and holding the initiative. Greater quickness permits rapid concentration of friendly strengths against enemy vulnerabilities. Done successfully, it will disrupt the enemy's plans and lead to piecemeal responses. Agility enables smaller forces to disorient and eventually defeat much larger enemy forces.

- **Initiative** means to set or change the terms of battle by action. It implies an offensive spirit in the conduct of all operations. It requires

a constant effort to force the enemy to conform to our operational purpose and tempo while retaining our own freedom of action. It requires audacity which may involve risk-taking and an atmosphere that supports it.

- **Depth** is the extension of operations in space, time, and resources. With depth a commander obtains the necessary space to maneuver effectively, necessary time to plan, arrange, and execute operations, and martial the necessary resources to win.

  In the offense, momentum derives from the correct use of depth. In the defense, elasticity derives from depth. Momentum and elasticity are achieved and maintained when:

  - resources and forces are concentrated to sustain operations over extended periods
  - adequate reconnaissance is provided beyond areas of immediate concern.
  - committed enemy forces are adequately fixed (geographically)
  - uncommitted enemy forces are interdicted
  - adequate air protection is provided
  - enemy's command and control system is disrupted
  - vulnerable rear areas are protected
  - combat forces project tactical operations deep into the enemy's vulnerable areas.

- **Synchronization** is the arrangement of battlefield activities in time, space, and purpose to produce maximum relative combat power at a decisive point. Synchronization is both a process and a result. Coordination of all available assets is only part of synchronization. The consequences of all coordinated actions should be the focus of the synchronization effort and not the actions themselves. Sometimes the consequences will be delayed in time or felt in other parts of the battlefield. In the end, the product of effective synchronization is maximum economy of force used where and when it will make the greatest contribution to success.

- **Versatility** is the ability of the commander to use his units in a variety of missions including war, peacekeeping, peacemaking, civil disturbances, natural disasters, and human rights missions. Versatility refers not only to the use of a unit but its training and composition. It also refers to the ability to mix and cross-attach unlike units for unusual missions. Versatility has to be emphasized at the training and staff level, as well as at the command level. The new operations manual still holds that the first four tenets are needed for success in battle, but for overall Army operations, including operations other than war, the fifth tenet of versatility is required.

Imperatives of War

Due to the abstract quality of the tenets of Airland Battle, they have been enhanced with the Imperatives of Airland Battle [FM 100-5 86]. They are:

- Ensure Unity of Effort

- Anticipate Events on the Battlefield
- Concentrate Combat Power Against Enemy Vulnerabilities
- Designate, Sustain, and Shift the Main Effort
- Press the Fight
- Move Fast, Strike Hard, and Finish Rapidly
- Use Terrain, Weather, Deception, and Operations Security
- Conserve Strength for Decisive Action
- Combine Arms and Sister Services to Complement and Reinforce
- Understand the Effects of Battle on Soldiers, Units, and Leaders

These imperatives are said to be "...historically valid, and fundamentally necessary for success on the modern battlefield." [FM 100-5 86]. They constitute another attempt at articulating a theory of winning in battle.

Principles of War

The Principles of War, originally developed in World War I [Fuller 21], are really a combination of Fuller's work, Clausewitz, Jomini [Jomini 1838], and experiences of the U.S. Army since its conception in the Revolutionary War. The principles of war have taken on more importance in current Army Operations Doctrine. They are listed in [FM 100-5 93] as:

- Objective
- Offensive

- Mass
- Economy of Force
- Maneuver
- Unity of Command
- Security
- Surprise
- Simplicity

Similar to the topics discussed by Clausewitz, these principles of war are part of a theory of war which can be thought of as prescriptive rules for winning in battle. The prescriptive form would be, "Develop a specific objective, always remember economy of force when planning the maneuver or the defensive portion of the battle, maximize your ability to maneuver and minimize the enemy's ability to maneuver, etc." The principles of war are accepted by several manuals, strategists, and armchair generals as unalterable, timeless principles, independent of the technology, geography, or political environment. However, these "timeless" principles have changed quite radically in the past 70 years and will continue to change as warfare itself changes. The history of past changes is presented in Chapter Two. Any theory of war for the future must be able to adapt to changing technology, environment, threat, and mission [Clausewitz 32].

The Dynamics of Combat Power

The following four *dynamics of combat power* [FM 100-5 93] combine to create the ability to fight. Indicating how important the dynamics of combat power are to the Army leadership is the following statement from the same manual: "Winning in battle depends on an understanding of the dynamics of combat power and putting them together to ensure defeat of the enemy." The four elements of combat power are:

- Maneuver
- Firepower
- Protection
- Leadership.

These four elements overlap with the principles of war previously discussed and with the battlefield operating systems to be addressed below. How the dynamics of combat power relate to either of these methods of organizing warfare is unclear in the literature yet important in establishing a logical structure for doctrine.

Battlefield Operating Systems (BOS)

Due to a need to categorize events and to organize critiques during the many evaluations, simulations, and live-fire exercises, Army leadership has developed the Battlefield Operating Systems (BOS). These are organized by function they perform. Many units of battalion size or larger will have most if

not all of the BOSs represented in their units, or staffs, or in their areas of responsibility. The seven BOSs, as listed in [FM 100-5 93] are:

- Intelligence
- Maneuver
- Fire Support
- Air Defense
- Mobility, Countermobility and Survivability
- Logistics
- Battle Command.

A key statement in the manual says, "To synchronize forces and effects on the battlefield, Army leaders use the technique of examining large, complex operations in terms of functional operating systems. The battlefield operating systems enable a comprehensive examination in a straightforward manner that facilitates the integration, coordination, preparation, and execution of successful combined-arms operations." The BOS will be examined for their value in building a structure to support existing doctrine and allowing straightforward measures of conformance to doctrine.

Selecting the Best Organization of the Battlefield

As battle has become more complex, more theories about how to win and how technology can affect the course of the battle have been proposed. Some theorists incorporate past successful frameworks for strategy while others

invent new ones. Few strategists have tried to use a structured approach in developing new doctrines or discrediting old theories. A structured approach would allow different doctrines to be evaluated objectively. New theories could propose different categorizations of the subelements of the same high-level principles, or they could introduce a new high-level principle that has not been discovered.

It is difficult to incorporate all of the principles, tenets, and imperatives found in FM 100-5 *Operations*. Many of the key subheadings within these different organizations overlap in their meaning, and each of the structures has the same overriding goal. Indeed, any structuring of combat doctrine must assume that the overall goal of a military unit in combat is victory. Any part of the structure must directly or indirectly support the goal. If subgoals are introduced, they must support the overall goal and are similarly supported by their own subgoals. A hierarchy of goals is implied. At the lowest level, a correctly formed hierarchical structure ties the critical actions on the battlefield to measures of concepts which support subgoals. Which actions are correct are determined by which actions give high enough values to the measures to allow the subgoals to be met. If enough correct actions occur, most of the subgoals are met which eventually cause the overall goal (victory) to be achieved. A hierarchical structure is desirable because an orderly analysis can be conducted which would identify actions on the battlefield that are both exhaustive and mutually exclusive. Aggregation techniques, which eventually must be used in any hierarchical structure that flows upward, are simpler when encased in such a structure. Chapter Three of this thesis develops a hierarchical structure based upon the Tenets of Army Operations.

1.3 Operation Desert Storm 1991

General Schwartzkopf, as the commander of Central Command and the operational commander of all Coalition Forces in southwest Asia during Operation Desert Shield and Operation Desert Storm, did not simply trust his intuition or his creativity. His last combat command in Vietnam had been over twenty years prior and differed greatly in climate, terrain, mission and type of unit. The Viet Cong and North Vietnamese were as different from the Iraqi Army as can be imagined. Equipment, strategy, technology, and boundary definition were all vastly different. The Iraqis had very sophisticated equipment, the North Vietnamese did not. The Iraqis had a strategy that envisioned political success long before battlefield struggles would be necessary while the North Vietnamese counted on a long struggle and used it to their advantage. The identification of the appropriate boundaries was much less of a problem in the Iraq War than during the Vietnam War. [Schwartzkopf 92] Given these differences and the long time that had elapsed since his two tours in Vietnam, it seems unlikely that General Schwartzkopf extrapolated his past combat successes to arrive at a strategy to defeat Saddam Hussein and the Iraqi Army. His strategic and tactical expertise and decision making ability was developed during his thirty years of military life, two tours in Vietnam, training at military schools, witnessing the Grenada invasion, reading about past successes and failures in battle, and involvement with many training and evaluation exercises. Experience, training, and reading are the ways in which the Army instills its doctrinal message into the thinking of its leaders. To understand how the success in the Gulf War supported or failed to support the value of AirLand Battle doctrine, two related questions should be asked:

- How well did the commander conform to Airland Battle Doctrine?
- How well suited was Airland Battle Doctrine to the battle he faced?

The structure of the operations plan of the War with Iraq shows that General Schwartzkopf used Airland Battle Doctrine as a basis for his plan. Deception, surprise, mobility, and concentrated firepower, all found in various places in the AirLand Battle literature, have been identified as guiding principles upon which he built his ground war strategy [Gulf War 91][Summers 92]. General Schwartzkopf states in his autobiography [Schwartzkopf 92], "The textbook way to defeat such a force would have been to hold it in place with a frontal attack (deception) while sending an even bigger army to outflank it (surprise and mobility), envelop it, and crush it (concentrated firepower) against the sea." The text in the parentheses is this author's idea of the doctrinal concepts behind each of the strategic actions. General Schwartzkopf's "textbook way" is the doctrine that he learned and helped develop during his career, not that given in any one textbook on the subject of strategy. Three weeks before the actual ground attack began into Iraq and Kuwait, he declared to LTG Yeosock, his Third Army Commander, "This is not a deliberate attack ... Go after them with audacity, shock action, and surprise." There is not much doubt as to what principles he believed would win the war.

Many have stated that the Airland Battle doctrine, the operative doctrine at the time of the conflict and outlined in FM 100-5 *Operations* 1986, was validated in this war. This statement assumes doctrine was followed and that the correct implementation of the doctrine caused, or significantly affected, the outcome of the war. Although it certainly sounds from his statements, that

many components of AirLand Battle tenets were guiding his decisions, one instance of success stemming from presumably high doctrinal conformance does not necesarily validate the doctrine. One might question whether General Schwartzkopf actually adhered to the current doctrine. One might also question the validity of attributing the success of the war to the adherence to doctrine. Any further analysis must address the questions of how the plan and execution conformed to doctrine, and how this affected the outcome of the battle. Although the Gulf War is not measured for conformance to doctrine in this paper, the measures developed in Chapter Three could be used directly with the data available from the Gulf War databases to estimate the level of conformance achieved.

1.4 Toward Developing A Model

1.4.1 Rational Decision Making

It would be tempting to conclude that the military actions taken during the Gulf War were correct because the outcome of the war was a decisive victory. Unfortunately, since war is known to be full of nondeterministic actions with unknown probability distributions, unknown relationships, and strong covariances between variables, correct or desired results are not always traceable to correct actions. Let us define a correct action as an action that follows established rules. With respect to combat:

- Correct actions do *not* imply desired results.
- Desired results do *not* imply correct actions (decisions).

Myron Tribus [Tribus 69] used the concept of indicators to help define rational decision making. According to Tribus' paradigm, a decision is made on the basis of indicators, and the outcome is determined partly by the decision and partly by the unknown factors. Based upon his ideas of the relationship between factors, the process, and the outcome, a schematic of the combat decision making process is shown in Figure 1.2.

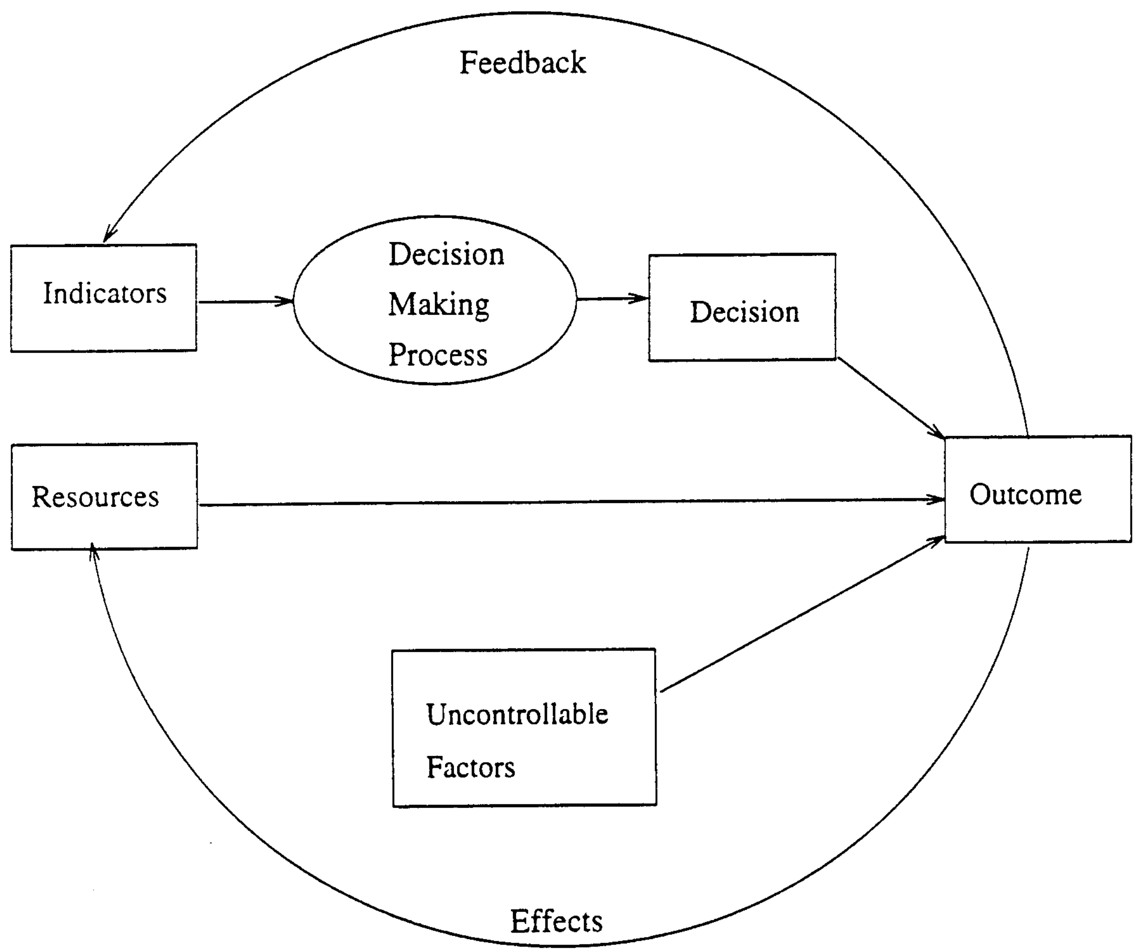


Figure 1.2: Schematic of the combat decision making process

The process by which the decision maker converts indicators into a decision is the object of study in decision theory. Tribus realized the confusion that is inherent in differentiating between *empirically* good decision making and *rational* decision making based upon the indicators. He listed a proposition that expresses the "bottom-line" approach to decision analysis:

Proposition X: Whether a decision was *right* or *wrong* is to be decided entirely on the results of the decision and not on the basis of the information available to the decision maker at the time he had to make the decision.

Proposition X is not considered correct in decision theory except for the case where indicators are undefined or unobservable. Where indicators can be observed, a different proposition is considered to be correct:

Proposition Y: Whether a decision was *right* or *wrong* is to be decided on the basis of the information available to the decision maker *at the time he had to make the decision* and not entirely on the results of the decision.

Tribus argues that Proposition X "...is an unworkable admonition because it says in effect, 'Always read the future accurately'." Therefore, one should judge a (combat) decision by judging the method used to make the decision. It follows that evaluators should have some other guide to assist them in evaluating decisions, aside from judging the result against the desired result.

To illustrate why Proposition Y is more rational than Proposition X, Tribus gives a hypothetical example: A general takes unacceptable risks in a battle, gets lucky, and wins. Do you promote him (encourage similar behavior in the future) or demote him? Proposition X says to promote him; Proposition Y says to demote him. The superiority of Proposition Y is obvious if your goal in future battles is to win.

1.4.2 A Preliminary Model

The scope of this dissertation is not to improve upon the efforts of many theorists, strategists, philosophers, and generals by rewriting U.S. Army doctrine. Doctrine will be described and then analyzed for meaning and structure. Methods of measuring conformance to the current doctrine will be developed. Based upon the graphical model shown in Figure 1.2, a preliminary Combat Outcome Function is offered:

$$CombatOutcome = F(C, E, R, O)$$

where:

C is the level of doctrinal conformance.

E is the technical and tactical level of execution of the battle.

R is the amount of resources in each of the critical areas.

O represents the other factors that are either unknown or immeasurable.

In the following paragraphs, the combat outcome model above will be reduced to $CombatOutcome = F(C)$ by controlling for or being able to measure the other variables. The rest of the dissertation is concerned with measuring the conformance to doctrine needed in this model.

1.4.3 Reducing the Model

The easiest factor to measure and to control in all models, simulations, and training exercises is the resource factor. For training exercises, the resource level is predetermined. For analytical models, one or more parameters must

be altered to modify the resource levels of either side. In simulations, depending upon the complexity of the model, information reflecting the size, capability, and replenishment rate for each resource can be included using parameters, distributions, or submodels. The Combat Outcome can be reduced to:

$$CombatOutcome = F(C, E, O)$$

The simplest combat model is one which reflects only the resources available to both opponents at the beginning of the battle. Such models may be deterministic models such as those that use Lanchester Equations [Lanchester 14], or may be simulation models which assign outcomes based upon probabilities of acquiring (targeting) enemy assets, hitting the target, and killing the target given that it was hit.

More complicated models account for the level of execution of the commander's orders. These models usually allow for decision making by the small unit commander or provide probabilistic methods for determining the level of execution by each unit. An example may be a stored probability for meeting a start time for a convoy. Or, a probability distribution of the convoy start time and length of trip may be used to make the time more realistic and to introduce some actual randomness into the simulation. Many of the unknown and unexpected occurrences that may happen on a convoy can be summarized by a probability distribution of the trip time. This assumes that the timing of the trip is the critical factor as opposed to the morale, fuel consumption, ammunition expended, or other results of a convoy operation.

Level of execution is now being included into many of the exercises by actually accomplishing the task (movement, river-crossing, etc.) with one

or more of the units involved. Distributed Interactive Simulation (DIS) is touted as the training exercise framework of the future by training experts from all four services. DIS will allow large scale exercises to be run at a designated geographical location with many of the participating units at remote locations. As the units participate, their actual execution of the commander's plan will be the execution level for the exercise. Notional units may also be included in the scenario. One will be not be able to differentiate between their simulated execution and the execution of actual units.

Execution by the unit of the commander's decisions is affected by

- **Friction** refers to anything that tends to slow down or degrade operations. Misunderstandings between commanders, weather, equipment breakdowns, and bad roads are all examples of contributors to the friction in the battle.

- **Inadequate Training** can be having the wrong personnel assigned to a task or may refer to failure to train available personnel to proper standards.

- **Lack of Ability** applies not only to the soldiers in the units but to the staff officers and commanders.

- **Morale**

In determining the influence of the above factors upon the outcome of the battle, difficulties arise. If one believes that only combat (i.e., actual battle) data may be used for this study, it would difficult to obtain the needed data. Very few U.S. Army leaders have had the opportunity to be tested in combat more than once or twice, using a given doctrine. Because each battle is

unique, unwanted and uncontrolled (from a scientist's point of view), it would be extremely difficult to develop a validated probabilistic model. Any one of several nondeterministic elements can predominate in a single battle. With no replication, there is no chance to determine the probability distributions of those elements or their effects upon the variance of the outcomes. A small database makes it difficult to ascertain the relationship between the deterministic factors. A superficial analysis can lead to extremely misleading generalizations of the effects of the various factors.

The unknown factors have always been troublesome for the combat modeler. Factors such as mechanical breakdowns, incompatibility between components, bad timing, poor communications, poor weather, fatigue, and a range of human emotions including stress, fear, and impatience can radically change the course of a battle even though the plan may have been good and the level of execution began high.

Conformance to doctrine is an area that has been relatively untouched and unmeasured. It is the focus of this research. Advancement in this area, both defining and measuring conformance to doctrine, should assist those who wish to either forecast the outcome of an upcoming battle or evaluate a doctrine that is a candidate for adoption by the services.

While much has been done in the area of recording and storing battlefield data (see Appendix A), the data remains raw data. Very little work has been done to develop methods that would transform the raw data into meaningful information that could be used as feedback to the commander so that he may improve his decision making. Directors of training exercises at the National Training Center, the Battle Command Training Program, and other Combat Training Centers subjectively appraise battle actions with respect to adher-

ence to known doctrine. Subjective evaluation depends on the creativity and intuition of the evaluators. Subjectivity, even when supported by some objective measures, is difficult both to defend and standardize. Some excellent work on measures of conformance to doctrine [Lamont 92], [Dryer 89], [Kemple and Larson 93] has been accomplished on a limited scale. All three papers addressed one measure of one tenet of Airland Battle Doctrine – Synchronization. The U.S. Army has not developed an objective, exhaustive, or consistent evaluation of a unit's conformance to doctrine.

1.4.4 Training Exercises

It is expected that the emphasis on training exercises will remain for the foreseeable future. Many leaders, returning from Operation Desert Storm in 1991, were convinced that victory would not have been as decisive had the units not been training for 10 years in similar conditions in the desert in southern California [Army 91].

The elaborate training exercises now occurring in at least four major training sites in the United States and Germany provide for controlled evaluation while allowing for much of the "fog of war" [Clausewitz 32] and some of the friction to be simulated. These sites can control terrain, weather and climate simply by making the site permanent. Similar scenarios are used with similar units. Controlling these many factors while still allowing confusion, misunderstanding, stress, fatigue, and some fear to be part of the exercise lends realism to the exercise while still providing for repetitions. Good experimental designs demand adequate repetitions which allow the experimenter to statistically evaluate the results while accounting for the variance of the results due to the uncontrolled aspects. Training exercises may solve the

problem of few or no repetitions. Many of the nondeterministic aspects of the battle can be either controlled or accounted for. This very important capability allows the effect of chance on the results of battles to be somewhat controlled. With resources (both enemy and friendly) and many of the uncontrollable factors accounted for, the model then becomes a simpler model with two main factors that influence the outcome:

$$CombatOutcome = F(C, E)$$

Although map exercises, wargames, and combat simulations are less helpful in alleviating lack of representation of the "fog of war" and friction, they too allow for repetitions which negate the effect of chance and much of the uncontrollable factors first alluded to in Figure 1.2. Proper design and testing would allow for more detailed analysis in determining the causes of success and failure.

1.4.5 Evaluating the Execution

In the past twenty years the U.S. Army has become extremely proficient at measuring the physical aspects of execution. In the mid 1970s, the Army Training and Evaluation Program (ARTEP) [TRADOC Reg 310-2 86] was designed to replace the antiquated Operational Readiness Test (ORT). The ORT had functioned as a scorecard for combat units in evaluating unit execution in major areas such as maneuver, targeting, communication, etc. It had not been designed to test or evaluate all of the areas which would indicate readiness to go to war. No thorough study had been done indicating the doctrinal concepts and associated actions that would be essential for victory or how to measure them. Summers [Summers 92] reports how the *management*

of a unit had become much more important than the training and *leadership* of that unit. This undesirable situation was partially caused by a lack of available doctrine for fighting the kind of war that had just ended in Vietnam. The ARTEP was developed to solve the problems of the ORT. It was developed through an intensive study of the critical missions of each type of unit. The developers had established exact standards for each task and subtask and the method of measuring the attainment of these standards was specified as well as the conditions for each task. As a result of developing and enforcing the new system throughout the entire training community, including the chain of command, the emphasis changed once again to training. The change was due mainly to the efforts of the Army Chief of Staff General Abrams, TRADOC Commander General William DePuy, and General Paul Gorman [Gabel 92]. The entire training effort was geared to the ARTEP, including budget, time, and resources. All classes were structured reflecting the approved Task, Conditions, and Standards. Soldiers and leaders knew the standards that had to be achieved in their area of expertise and knew they would be evaluated every 12–24 months as a unit during a training exercise.

Unfortunately, it was impossible for each soldier to be trained on every task with proper proficiency. Realizing this problem, in the 1980s, the training community introduced the METL (Mission Essential Task List). Using the knowledge and experience of the division commanders and their staffs, selected missions of the division appeared on the METL. Each brigade received the division's METL along with its own brigade METL. Essentially, this action had the effect of pruning the mission tree that had become too dense. None of the missions could get the proper training emphasis before

such pruning. After the pruning, a brigade would have 5 to 10 major missions rather than 20 to 40 missions. The brigade commander was now able to select an appropriate number of missions for the subordinate battalions. Similarly, the companies and platoons received METLs from their parent unit. For the first time the entire tactical Army had missions with standards that were uniform, attainable, and trainable. Each mission was justified based upon the missions assigned to the next higher unit.

To assist training realism and improve evaluation procedures, several Combat Training Centers (CTCs) were developed in the 1980s. The CTCs are large areas, usually capable of accommodating a brigade scenario. TRADOC stationed professionally trained OPFOR units at each of the sites and large fire zones were established that allowed close air support, artillery, MLRS (Multiple Launched Rocket System) and direct fire weapons to be coordinated as they would have to be coordinated in war. Each center has its own high-technology data collection center which includes cassette tapes, video tapes, position data for every unit and most of the vehicles, and a recorded history of the battles. Data such as expenditure of ammunition, the accuracy of the artillery, air defense, armor, and infantry, the planned targets and the fired targets is stored for each battle. This type of data collection effort in a realistic but controlled environment gives analysts a richer cache of data.

The commanders of the CTCs have developed a structured and comprehensive system of After Action Reviews (AARs). The evaluators and the players from the most recent battle discuss the areas of apparent weakness and strength. The players explain why certain actions were taken and others

delayed or omitted. The evaluators identify measures that indicate deficiencies in either execution or planning. The unit being evaluated and trained is advised on matters ranging from misplaced guards to bad communication practices to ignoring the tenets of Airland Battle. The leaders are shown video tapes, listen to cassette recordings of radio transmissions, and view reconstructions of the battle on terrain maps. The evaluators and controllers make every effort to give the unit and its leaders the most feedback they can offer both in terms of raw data and interpreted results. Units leave the CTC with a large "take-home package" (THP). Unfortunately, many officers admit these THPs are rarely studied after returning from the exercise in California. An effort currently underway is attempting to devise more accurate, objective, and consistent measures of unit performance [Holz 94]. Much of the projected future work will be to develop ways of measuring units performance with respect to doctrinal guidelines.

By conducting interviews of OPFOR leaders, evaluators, soldiers with National Training Center experience, and from this author's personal experience, the summaries of unit performance are either low level or high level with little structure that would connect the two types of evaluation. The high level critiques concern doctrinal issues and are quite subjective with little or no objective quantitative data to support them. This will continue to be the case until there exists a system that provides evaluators the ability to quantitatively assess a unit's conformance to doctrine. The low level critiques and evaluations are very specific and focus on concrete corrective action. They are geared toward small unit tactics as well as personal practices. There is no stated structure underlying the doctrine which allows the evaluators to directly connect low level actions on the battlefield to the tenets

of Airland Battle. If such a structure exists, it has not been published nor is it being used. Connecting the two levels of evaluations would serve to justify corrections at the lowest level and provide a guide for making corrections at the highest level.

Because execution can be adequately measured, mainly during training exercises, the Combat Outcome Function reduces to:

$$CombatOutcome = F(C)$$

or simply a function of doctrinal conformance. We reiterate that this function is meaningful only if there are a standard and constant doctrine, and the analysis accounts properly for execution, resources, and other unknown or immeasurable factors. Using the power of simulations, together with the complete instrumentation of the National Training Center (NTC) and the ability to control resources and the environment during large training exercises, for the first time all of the factors from the original model (proposed at the beginning of this section) can be controlled or measured. Measuring the conformance to doctrine may now feasible.

With the entire U.S. Army supporting those missions that are necessary (METL) while meeting standards designed to be reachable but challenging, the concept of doctrine seems less important or urgent. Why be concerned about higher level doctrine when all of the important missions are being trained and tested? The reason becomes apparent when a commander must choose a mission or a course of action and fight the enemy using that decision. The decision of which tasks must be accomplished and which units will be assigned those tasks is a doctrinal problem. How to avoid being forced into unwanted situations and methods for extracting a unit out of difficult

situations is also addressed by doctrine. Doctrine does not normally involve technical proficiency. In fact, doctrine *assumes* that the units have technical and tactical proficiency. Achieving technical and tactical mission standards is the first step towards defeating the enemy. Surpassing the standards in the right mission in the right place at the right time is the job of commanders armed mainly with leadership and doctrine.

1.5 The Problem

1.5.1 Statement of the Problem

Doctrine prescribes to the leaders of the U.S. Army how to fight. It consists of experience, written materials, and abstract ideas that give direction for actions on the battlefield. It has not been developed to be specifically measurable or objectively calculated, but rather to guide, motivate, inspire, and teach commanders, staffs, and soldiers. Because it is difficult to relate abstract ideas and experience that are part of doctrine to specific actions, the U.S. Army is left with no objective way of measuring conformance to doctrine.

Actions that occur during a battle or training exercise can usually be measured. However, the actions need to be measured in a meaningful way – one which indicates their effects upon the battle and its outcome. A way of giving the commander feedback on his *actions* rather than on his *results* needs to be developed so that he can appropriately alter his actions to achieve victory. Doctrine is what *should* be done; conformance to doctrine indicates the degree to which what *is* being done corresponds to what should be done. The commander needs feedback on conformance to doctrine to improve future

performance. Measures of results provide evaluative information; measures of conformance to doctrine provide diagnostic information. Diagnostic information is more valuable than evaluative information because it indicates how improvement can be made. Wetherbe addressed the value of feedback when he stated, "The power of feedback is in its ability to increase effort in the measured area. It is therefore quite important that the feedback be well designed so as to effect improvement or additional effort in the correct and most critical areas" [Wetherbe 84].

The problem that this research attacks is the problem of devising and evaluating a set of diagnostic indicators that can be useful in measuring the extent to which a commander has been taking actions that are appropriate according to doctrine. The indicators must be objectively computable from data of the kind currently collected and maintained in battle exercises. The evaluation should show that when they are applied to a specific battle and compared to the opinions of experts who have analyzed the same battle, the indicators are judged to measure what they purport to measure. No attempt will be made to gather experts' opinions as to the potential usefulness of the indicators; the experts available to the author are highly biased in favor of the indicators, and such opinions are speculative anyway.

1.5.2 Objective

The objective of this research is to develop a consistent and objective method of measuring a unit's conformance to doctrine. Specifically, we will derive diagnostic measures of conformance, based objectively on existing and available battlefield data, that accurately compare battlefield actions by a mechanized infantry task force with actions prescribed by Army Operations Doctrine.

The following tasks will support this objective:

1. Find or develop a suitable method for analyzing doctrine and identifying the critical concepts contained in it.

2. Find or develop a method for evaluating the suitability of a measure with respect to the critical doctrinal concept that it measures.

3. Apply the method from 1 above to the Tenets of Army Operations.

4. Develop doctrinal measures for the two tenets of Agility and Synchronization that comply with the evaluation standards developed in 2 above.

1.5.3 Procedure

Published methodologies from various modelers and analysts are reviewed and their concepts synthesized. The result is both a systematic method for conducting the analysis of doctrine and a scheme for evaluating the newly developed measures.

The four tenets of Army Operations are subjected to this analysis resulting in a structure built under the top-level tenets.

Measures are developed and evaluated for each of the concepts that relate to the tenets of Agility and Synchronization. The measures must relate to the concepts they evaluate but must be computed from available battlefield data, as described in Appendix A.

Once the measures have been developed, FORTRAN programs (see Appendix C) allow easy calculation of the measures given the correctly formatted battlefield data.

Training battles from the NTC were chosen that had the following attributes:

- Digital database stored and available at ARI-POM, Monterey, California
- Relatively modern equipment and weapons
- A rich mix of weapons
- Similar resources
- An After-Action Review (AAR) is available
- The battle is between two live, active forces

The values for the developed measures are calculated for each battle. The results are compared to the subjective evaluations of at least ten experienced Army officers who are shown a computerized replay of the battle and given a synopsis of the AAR.

The results of the test show support for the measures of Organizational Agility, Physical Agility, Fire Support BOS, Mobility, Countermobility, and Survivability BOS (Defense), Weapons Usage, and Invulnerability. All of these measures, as well as the components they are designed to relate to, are developed in Chapter Three.

CHAPTER 2

Literature Review

2.1 Overview

In this chapter, we first review the main contributions to and the foundations of military doctrine. From Sun Tzu to modern military theorists such as Falls or Bretnor, doctrine has been defined, developed, and improved. We address the publications on current Army doctrine in Section 2.3. The chief publication on this topic is FM 100-5 *Army Operations.* In Section 2.4, we review the brief history of doctrinal conformance publications. Military modeling is reviewed in Section 2.5. A few widely used combat models are discussed in Section 2.6. In Section 2.7 we review the literature pertinent to hierarchical structures and analysis techniques appropriate for breaking down doctrinal concepts into measurable parts (low-level acivities). In Section 2.8 we review two viable techniques for aggregating results from doctrinal conformance scores for low-level activities. Finally, several methods for computing combat power are discussed in Section 2.9.

2.2 Past Contributions to Current Doctrine

In ancient times, doctrine was not often written. It was implemented by and peculiar to each general. The military leader was educated by learning about what failed and what succeeded in the past. As trial and error paved the way towards the best strategy of the day, military theorists such as Alexander, Xenophon, Polybius, Marcelinus, and Julius Caesar learned the lessons of the past and established rules for conducting war [Gat 89][vanCreveld 91].

Rapid technological progress complicated the establishment of general principles of combat. "...Nonmilitary technologies played a decisive role in shaping warfare in general and strategy in particular.... Technology itself grew partly in response to military needs. As always, the two factors interacted, and by so doing pushed development along" [vanCreveld 91].

Machiavelli, during the Enlightenment in the 16th century, was the first to formulate the principles of strategy and tactics [Machiavelli 65]. Machiavelli believed that certain principles, if once proven to work, will continue to be valuable, generalizable rules that could apply to battles in the future. Fuller[Fuller 21], Bretnor[Bretnor 69], and Jomini [Jomini 1838] should be included in the Machiavellian camp as believers in the 'timeless principles' concept.

As Napoleon was conducting his great marches through Europe and establishing himself as the world's foremost strategist and general, it is generally agreed that modern warfare, as we know it, began [Gat 89]. Jomini and Clausewitz were the top writers of military art. Although Jomini [Jomini 1838] believed certain principles to be timeless, Clausewitz does not belong in the Machiavellian group. Clausewitz believed that principles must

change as the face of combat changes due to the change of economy, society, and technology [Clausewitz 32]. In fact, in Book Three of his work, *On War*, Clausewitz took his relativism one step further and discarded any possibility of helping the commander on the battlefield with a set of rules or a specified model.

Azar Gat, the author of *Military Thought*, and the renowned Bulow, however, disagreed with Clausewitz' thoughts on rules [Gat 89]. Bulow stated, "Genius, dear sirs, never acts contrary to the rules" (quoted from Gat [Gat 89]). There is evidently disagreement about the value of proposing and espousing principles of warfare.

Clausewitz is arguably the most quoted military thinker ever (some would argue that the work of Sun Tzu [Sun Tzu 73] is better known and more widely discussed). Although Clausewitz never finished his work, *On War*, it has been published and translated many times over the past 160 years and is studied at the US Army Military Academy and several officers professional development schools. There are eight books contained in his work, with the following topics:

The Books in Clausewitz' *On War*

The Nature of War

On the Theory of War

On Strategy in General

The Engagement

Military Forces

Defense

The Attack

War Plans

Note: As the third attempt at an English translation of *On War*, Howard and Paret's [Clausewitz 32] version has become the standard in the U.S. Military schools. The quotes from Clausewitz throughout this paper come directly from their translation.

In Clausewitz' third book, the titles of his chapters represent what he felt to be crucial areas to be considered when planning and running a campaign. A campaign is simply a series of related operations designed to support an overall purpose.

Clausewitz' Chapters on Strategy

Military Virtue of an Army

Boldness and Perseverance

Superiority of Numbers

Surprise

Stratagem

Assembly of forces in space and time

Strategic Reserve

Economy of Forces

This list of chapter titles became the initial principles of combat.

2.3 Twentieth Century Contributions

In this section there are four authors' ideas of how the guidelines for combat should be stated. The presented organizations address overlapping issues [Fuller 21] [Falls 61] but also introduce new concepts such as vulnerability [Bretnor 69].

Major General J.F.C. Fuller was a British general famous for both his actions during World War I and his writings on the theory of war shortly thereafter. If one compares Clausewitz' chapter titles to Fuller's principles of war, many similarities appear. Fuller [Fuller 21] lists his original set of principles of war as:

Fuller's Initial Principles

Objective

Mass

Offensive

Security

Movement

Three years later Fuller added two more principles [Bretnor 69], named **Economy of Force** and **Cooperation**. After being modified several times in the next ten years the 'principles' became the following [Bretnor 69]:

Fuller's Final Principles

Direction

Concentration

Distribution

Determination

Surprise

Endurance

Mobility

Offensive action

Security

In 1961, Cyril Falls published his views on the art of war [Falls 61]. In this volume he states his disdain for the principles of warfare, essentially agreeing with Clausewitz. Falls proposed five principles that should be viewed as "warnings of what will probably occur rather than guides for action on the battlefield" [Falls 61]. The author's five principles are in Table 2.1.

Bretnor, [Bretnor 69] a well known 20th century military critic and theorist, states that principles of war do not capture the entire theory of modern war. Because we need principles to allow us to predict or control the processes and relationships of war, Bretnor stresses we include two essential elements of the process that have typically been left out – the enemy and vulnerability.

Table 2.1: Falls' Principles of Combat

Falls' Principles	Explanation
Concentration	Superior strength at the vital point. (Notably missing are the words 'at the vital time'.)
Protection	Actions to guard against surprise attack. Advanced and flank guards will often save the main body from deploying and undergoing needless fatigue.
Surprise	The most effective of all keys to victory, surprise is inexorably tied to concentration. The three types of surprise are Place, Time, and Weight.
Aggressive Reconnaissance	"If the choice is between fighting for information and fighting in the dark, the commander would not hesitate to opt for the former."
Maintenance of the Aim	"The commander does not allow himself to be diverted from his aim by secondary objectives; nor should he fail to persevere in his attempt to reach it because his task proves more difficult than he had expected."

He advances the view that processes and relationships of war all have two things in common, Might and Vulnerability. He defines them as follows: Might (friendly or enemy) is positive destructive physical force. Vulnerability (friendly or enemy) is negative ability to withstand destruction by physical force. "All the other factors of war can be nothing more than their (Might and Vulnerability's) determinants" [Bretnor 69].

Bretnor also contributed his 'phases of war' which are forced into order by their functions and tied to the opposing force's phases by time. For our purposes, the table below contains Bretnor's main contributions to doctrine.

Bretnor's Phases of War		Main Factors
1	Preparatory	Might
2	Logistics	Vulnerability
3	Maneuver	Time
4	Weapons	

In the mid 1970's, General William Depuy developed a doctrine that was purely prescriptive in nature for the first time in U.S. military history [Gabel 92]. With the support of the Chief of Staff of the Army, he told the Army community the way a battle of the future should be fought. Depuy's doctrine in FM 100-5 [FM 100-5 76], while still influenced by the principles of war, was developed to support the strategic, operational and tactical environment that the U.S. perceived in the post-Vietnam War world. Gabel [Gabel 92] describes the environment at this time and the justification for the prescriptive doctrine. This version of FM 100-5 does not clearly state the principles upon which the remainder of the doctrine is based. The prin-

ciples of war were left completely out of the manual. On page 3-3 there is a small box above which is written, "To win a battle, four prerequisites must be met". It appears that these four prerequisites make up a large part of the 1976 Active Defense doctrine (see Table 2.2).

Table 2.2: DePuy's Prerequisites of Victory

	DePuy's Battlefield Dynamics
1	Adequate forces and weapons must be *concentrated* at the critical times and places. The combination is combat power.
2	The battle must be *controlled and directed* so that the maximum effect of fire and maneuver is concentrated at decisive locations.
3	The battle must be fought using *cover, concealment, suppression, and combined arms teamwork* to maximize the effectiveness of our weapons and to minimize the effectiveness of enemy weapons.
4	Our teams and crews must be *trained to use the maximum capabilities of their weapons.*

2.4 Current Doctrine

The Field Manual FM 100-5, 1993 describes itself as the "...Army's keystone doctrine." The key concepts of operations in this manual are found in Chapter Two, *The Fundamentals of Army Operations.* The first funda-

Table 2.3: Comparison of Past and Present Principles of War

Current Principles	**Fuller's Principles**
Objective	N/A
Offensive	Offensive Action
Simplicity	N/A
Unity of Command	N/A
Mass	Concentration
Economy of Force	Distribution
Maneuver	Mobility
Surprise	Surprise
Security	Security
N/A	Direction
N/A	Determination
N/A	Endurance

mentals are "The Principles of War." However, these principles are slightly different from Fuller's [Fuller 21] principles of war (see Table 2.3).

The next heading in Chapter Two is "The Tenets of Army Operations." Four of these tenets were originally introduced in 1982 as the Tenets of Air-Land Battle [FM 100-5 82]. The tenets, already described in Chapter One, are listed below.

Tenets of Army Operations

Agility

Initiative

Depth

Synchronization

Versatility

The third set of principles that are contained in FM 100-5, 1993 is "The Dynamics of Combat Power." These have been in the Operations Manual for over 10 years and correspond closely to the *Battlefield Dynamics* in the 1976 version of the manual. The four dynamics listed in the current version of FM 100-5 are:

Dynamics of Combat Power

Maneuver

Firepower

Protection

Leadership

Finally the "Imperatives of War" have recently been removed from the Operations manual but have been taught as part of Army doctrine for over a decade [FM 100-5 86]. The imperatives are:

Imperatives of War

Ensure Unity of Effort

Anticipate Events on the Battlefield

Concentrate Combat Power Against Enemy Vulnerabilities

Designate, Sustain, and Shift the Main Effort

Press the Fight

Move Fast, Strike Hard, and Finish Rapidly

Use Terrain, Weather, Deception, and Operations Security

Conserve Strength for Decisive Action

Combine Arms and Sister Services to Complement and Reinforce

Understand the Effects of Battle on Soldiers, Units, and Leaders

The last four groups of doctrinal principles either are currently taught or have been taught to Army soldiers and leaders within the last 2 years (1993–Present).

FM 100-5 is not the only manual that addresses Army doctrine. FM 100-1 [FM 100-1 91] addresses how the Army's Strategy fits into the National Military Strategy which supports the National Security Strategy. At the lower level of operations, each major functioning element (i.e., Infantry, Armor, Fire Support, etc.) has its own doctrinal manual that states more specifically how to fight. An example of this type of manual is FM 6-20, *Fire Support in the Airland Battle.* There are also doctrinal manuals addressing combat in various environments. FM 90-3 expresses Desert Operations and FM 90-6 expresses Mountain Operations [TRADOC Reg 11-7 86].

2.5 Doctrinal Conformance

The issue of doctrinal conformance has just recently been addressed in the military/technical literature. The Director of the US Army TRADOC Analysis Command in Monterey, California (TRAC-MTRY) initiated a study in 1991 entitled *Battlefield Enhanced Analysis Methodology (BEAM)* [Fernan 94]. The study director was initially Major D. Dryer who had recently worked in

this area for his Masters thesis [Dryer 89]. The BEAM study [Fernan 94] coincided with Major R.W. Lamont's Master's thesis entitled *Direct Fire Synchronization* [Lamont 92]. Dryer and Lamont chose to measure the Synchronization of direct-fire weapons by graphically depicting the number (density) of weapons that could target a given location within the area of operations. Different colors represented different densities. The user of the program could watch as the densities changed for each location throughout the battle. The commander could check for correct alignment of the unit's weapons systems and the enemy's strong points. He could also check for overall concentration throughout the area of operations. The calculations took terrain and line-of-sight (LOS) into account, as well as the range of the direct-fire weapons. The direct-fire weapons system studied was the M16A2 Rifle. Further studies were planned for other direct-fire weapons. When Captain Fernan became the study director in 1992, he used the previous work by Dryer, added some of the work accomplished by Captain Nelson [Nelson 92] on graphical representation of units in combat, and enlisted the help of Drs. Kemple and Larson of the Naval Post-Graduate School, Monterey, CA. Kemple and Larson [Kemple and Larson 93] developed a method for calculating Synchronization of indirect-fire weapons and addressed the possibility of extending the doctrinal measures to Agility, Initiative and Depth. The final BEAM report was published in January, 1994.

Ingram and Short [Ingram and Short 91] proposed an approach for developing measures of command and control. They recommended tying the measures to the tenets of AirLand Battle doctrine because the elements involved in Command And Control were *the* key elements used in the discussion of the four tenets in FM 100-5. Stone and Jones [Stone and Jones 92] used

Ingram and Short's work to develop several measures of effectiveness (MOEs) of Command And Control that were closely related to the Tenets of AirLand Battle. Their purpose was to use the measures with a newly developed combat model called EAGLE [Ogren 89]. Stone and Jones used independence and measurability as their criteria for accepting an MOE.

There exists no other open literature on measures or measuring conformance to doctrinal principles. There is a great deal of literature concerning MOEs as documented by Lieutenant Colonel Pawlowski [Pawlowski 93]. Measuring effectiveness is different than measuring conformance to doctrine. An MOE is a robust quantitative expression of the degree to which the system under evaluation meets its objectives [DARCOM Pam 79]. Using the definition established by the U.S. Army, an MOE must measure actions or status related to the objectives of the exercise, simulation, or wargame. The objectives may not be tied to doctrinal principles or even to the performance of the unit conducting the mission.

2.6 Contributions to Military Modeling

Although we are not attempting to perform classic combat modeling in this dissertation, there are certain principles of combat modeling that must be taken into account. The purpose of most combat models is not measurement of conformance to doctrine. Typically, their purpose is to predict the outcome of a battle. Another purpose may be to analyze the effects of new weapon systems or to train leaders. Many of the combat models that have been accepted by the Army community address key elements such as principles of movement, combat power measurement, and command and control.

One of the most commonly cited publications on combat modeling is *Military Modeling*, edited by Wayne Hughes [MORS 84]. It contains a selection of papers from the recognized leaders in combat modeling. The 46-page overview contains a good discussion of the state of the art of military modeling, as well as the foundations of general modeling. The volume contains explanations of military modeling techniques, a survey of some of the most popular ground combat models (see Chapter 4, by Wilbur Payne), and a good explanation of William of Occam's famous quote, "Pluralites non est ponenda sine necessitate" (Multiplicity ought not to be posited without necessity – an expression of the parsimony principle in modeling).

James Taylor's work on Lanchester Equations [Taylor 76, Taylor] showed how differential equations could express battle dynamics. The seminal work in this area was done by Lanchester in his famous paper, *Aircraft in Warfare – The Dawn of the Fourth Arm* [Lanchester 14]. That modern control theory extends the applicability of Lanchester equations for analyzing combat decision-making was a significant contribution by Stuk and Young [Stuk and Young 87].

In *Operations Research* [Morse and Kimball 70] the authors present various approaches to high-resolution combat modeling. The process of development of an MOE and the difference between it and a measure of performance (MOP) support the discussion and subsequent methodology of analyzing a combat system hierarchy.

Myron Tribus' book entitled *Rational Descriptions, Decisions, and Designs* [Tribus 69] addressed the issue of rational decision-making when probability or uncertainty is involved. He formally proposed that decision-making should be rationally based upon known information and its quality judged

not on the results but on the process used to make the decision. Tribus supported parsimony as a principle in modeling and stated its importance for model accuracy as well as model efficiency.

The Army's manuals have been instrumental in providing clear and accepted definitions of normally vague terms. The two documents utilized for their definitions were Field Manual 100-5, *Army Operations* and TRADOC Pamphlet 11-9, *Blueprint of the Battlefield.* The clarifying discussions of levels of combat, the role of each size of unit, and the separation of the battlefield activities into Battlefield Operating Systems (BOSs) were used extensively in Chapter Three. The three-year difference between publication dates of the two manuals resulted in several conflicts in definitions and BOSs. [FM 100-5 93][TRADOC Pam 11-9 90]

2.7 Combat Models

JANUS [Inventory 91] is a combat simulation model developed in the 1980's for both training and analysis. It simulates mainly ground combat, although it allows for limited air and naval support. As a high-resolution combat simulation model, each entity (weapons system, logistics system, commander) is played. The database for the NTC battles can be reconfigured to be compatible input data files for a JANUS battlion-level battle [Dryer 91]. The training value of the measures of conformance to doctrine could be dramatically increased by allowing a commander and his staff to replay the battle on JANUS that they had recently fought at NTC. The commander would be free to change his plan or one of his decisions during the battle. The effect on both the conformance measures and the battle outcome would be

immediately apparent.

Battalion Brigade Simulation (BBS) [MOSAIC 94][Inventory 91] is a combat simulation model designed for training battalion and brigade staffs and commanders. It is used extensively in a program called the Battalion Commander Training program (BCTP) where future battalion commanders receive intensive tactical training during field and computer exercises. Because doctrinal training through tactical exercises is the objective of BBS, it appears that many of the doctrinal measures developed in Chapter Three would be appropriate for diagnostic use. The BCTP, equipped with BBS and possibly tied into JANUS for high-resolution simulation, would also be able to test and possbily modify the measures of conformance.

EAGLE [MOSAIC 94] is a low resolution model that operates at the Corps or Division level. It is one of the first large scale combat simulation projects to be written entirely in an object-oriented language. It is a flexible, deterministic model that has been used for analysis [MOSAIC 94] and training [Ogren 89]. There is no randomness built into EAGLE, except for any randomness present in the high resolution models that are linked to it. Human interaction is allowed in the decision-making role. EAGLE would be a possible platform from which doctrinal conformance measures could be introduced into the command and control of a large unit. Stone and Jones [Stone and Jones 92] have already explored using MOEs to measure an EAGLE user's doctrinal command and control performance.

2.8 Analysis and Synthesis Techniques

In 1970 a paper was published on generalizing the rules for hierarchical structures by Mesarovic, Macko, and Takahara [Mesarovic et al. 70]. In each of the hierarchies that they examined, each element in the same level shared the common characteristics of:

- A certain relationship to the parent element in the next higher level
- A certain relationship to the child element (if it existed) in the next lower level
- A relationship to the group of elements sharing the same level

Their term for this type of structure was *stratified hierarchies*. Below is a formal description of stratified hierarchies' characteristics.

- Each stratum (or level) of hierarchy deals with the very same system. the only difference being that different strata provide different descriptions, or different models for observing the system.
- Each stratum has its own unique set of terms, concepts, and principles.
- The selection of strata for describing a particular system depends on the observer and his knowledge and interest in the control of the system. For many systems, however, there may be some strata which appear to be natural or inherent.
- There exists an asymmetrical interdependence between the functioning of a system on different strata. The requirements for proper system

functioning at any level appear as constraints on the meaningful operation of lower levels, effect of the lower levels on the higher levels.

- Understanding of the system increases by crossing levels: by moving up the hierarchy, one obtains a deeper understanding of system significance with regard to the goals that are to be achieved, while in moving down the hierarchy, one obtains a more detailed explanation of the system's functioning in terms of how those goals can be carried out.

Rasmussen and Vicente [Rasmussen 85, Vicente and Rasmussen 89, 90] used Mesarovic's generalized hierarchy rules to make their own framework called the "Abstraction Hierarchy." They used this framework to help design and improve human-machine systems. Since combat is a human-machine system, Rasmussen's framework was initially thought to be appropriate for the analysis of doctrine. The Abstraction Hierarchy contains 5 strata, each with its own criteria for membership. Stratum One contains goals and objectives. Stratum Two contains priority measures. Stratum Three contains general functions and activities. Stratum Four contains physical activities and processes. Stratum Five contains appearance and configuration of objects. The structure for doctrine needed to be more flexible to allow identified elements in Strata Three or Four to be measured directly. Stratum Two would very difficult to identify with doctrinal concepts because the priorities of the tenets and their underlying components are explicitly left out of written doctrine. The exercise in attempting to use the Abstraction Hierarchy was beneficial in that it aided the process of breaking down each of the components of the tenets into comprehensive subcomponents.

In addition to psychology, I looked to other areas where hierarchical analysis was performed. Functional analysis, means-ends analysis, and systems analysis are all commonly used methods for superimposing a structure or framework into an existing system. Each method of analysis is actually a different method of representation or modeling.

Principles of modeling are widely discussed in the literature of psychology (e.g., [Medin and Ross 92, Chapter 8]) in connection with models of semantics and of memory. In this literature, hierarchical model structures are preferred to more complex ones, *a posteriori* evaluation of models is done mostly on the basis of prediction ability, and *a priori* evaluation is often based on feature similarity, that is, a recognizable correspondence of elements or features in the model to those in the real world. these requirements are comparable to those of parsimony, fidelity, and applicability reviewed below.

The literature of systems analysis, with its techniques of general systems theory, articulates many modeling principles. Systems-theory models are typically not hierarchical; they describe a system at a single level of abstraction and formulate a picture of a system in terms of its inputs and outputs, with feedback of outputs to inputs. The aim of modeling in this field is generally to provide control of the system by manipulating inputs on the basis of monitoring the outputs. A representative textbook that includes modeling principles for systems analysis is [Wetherbe 84].

A challenging problem in systems analysis is that of decomposing a system into parts. A general principle espoused by Wetherbe and other is that the parts should be defined so that there is minimal interaction among them. In the feedback-control context, a model is better if its elements have fewer inputs and outputs. These principles correspond closely to the orthogonality

and parsimony principles found in other literatures. The principle of parsimony is widely found in systems analysis literature. See, for example, the discussion on the value of information in [Wetherbe 84], Chapter 3.

Systems analysis literature advocates hierarchical modeling in the development of software (e.g., top-down development in [Wetherbe 84], Chapter 9). Orthogonality is espoused in the form of advice to define subroutines that minimally interact (have minimal data flow between them), and parsimony is espoused in the form of admonitions for simplicity in several contexts.

Structured Modeling, introduced by Arthur Geoffrion [Geoffrion 87], is a completely different methodology for analyzing systems and then modeling them. It was first introduced as a methodology for assisting mathematical programmers in designing or modeling a correct mathematical programming model of a system (or problem). Its first step, that of drawing a genus graph, is particularly useful in building an initial hierarchy from a set of existing model elements or variables. A genus of elements is said to "call" another genus if the calling one depends on the called one for its meaning (e.g., "purchase" calls "customer," "item," and "seller"). The genus graph is a useful tool in structuring a model because it provides guidance by providing levels of abstraction (a useful concept from Geoffrion's structured modeling is that structured relationships in almost any kind of model should be among entities that do not differ greatly in their level of abstraction).

A paper by Young [Young 94] presents five principles of basic representation that hold true for most analyses. The four concepts are:

Orthogonality Variables used in representing parts of a system should be as distinct as possible. An increase or decrease in one should not induce an increase or decrease in the other. Structures are more explicit and

easier to discern if the representations are orthogonal.

Applicability The variables chosen should be relevant to the cause or purpose of the representation. The effect or indication of the variable should be significant.

Measurability Each of the variables used in the model or representation should be judged on its:

- Ease in measuring
- Accuracy and precision of the measurements
- Repeatability of the measurements

Parsimony In representing a system, parsimony is a principle that has been successfully used by many modelers. Sometimes referred to as 'Occam's Razor', parsimony calls for choosing the simplest of mathematical combinations of variables, both in form and in number. It allows for more manageable error assignment, better accuracy, less sensitivity to random error, and greater generalizability.

Generalizability Robustness. Ability to remain valid in a variety of different environments and ranges of variable values.

The first three principles refer to the individual variables or categories selected to represent a system's main concepts. The fourth principle, parsimony, applies to the number of variables or categories used and to the manner in which the variables are combined to represent the mathematical relationship between the distinct elements of a system. Parsimony, together with generalizability, apply to the method of combining the major elements

into a model. Although Young has presented them as principles, these same characteristics can be found as desiderata for good models in several writings. Torgerson [Torgerson 92] cites parsimony and reasonableness as his two guides in modeling. Hughes' book on military modeling [MORS 84] lists a large number of desirable traits of representation, but then reduces them to:

MORS Military Modeling Traits

Simplicity

Transparency vs. Opacity

Realism vs. Relevance

Reproducibility

In 1978, the Army Models Review Committee listed fourteen model properties that would be used for evaluating models. Notably absent from the list below is parsimony, although *visibility to the analyst*, *visibility to the user*, and *resources required* are all related to this principle.

AMRC Model Properties

Consistency

Enrichment potential

Experimental validity

Military realism

Physical reasonableness

Visibility to the analyst

Credibility

Flexibility

Interface potential

Resources required

Responsiveness

Sensitivity of the model

Technical user capability

Visibility to the user

Taylor, a well-known military modeler [Taylor 79], described four important model desiderata:

<u>Taylor's Model Desiderata</u>

Operational realism

Degree of abstraction

Reproducibility

Flexibility

Finally, Giordano and Weir [Giordano 85] addressed the process of modeling and listed three characteristics of a good model:

<u>Giordano and Weir's Model Metrics</u>

Fidelity

Cost (to model *and* use)

Flexibility

Giordano's characteristics are of the entire model and not to be taken as traits of individual variables being considered for inclusion in the design. It appears that the question of parsimony is addressed by Giordano and Weir implicitly in the characteristic of cost. The cost of modeling can be in terms of money, time, programming, or data acquisition and verification. Most of these costs can be reduced through greater use of parsimony. But parsimony does more than reduce cost. It also protects against worsening real accuracy while improving face accuracy. Adding an irrelevant variable reduces regression error in fitting the past, but increases forecast error: this can be demonstrated by fitting a linear model through data that has been generated from a constant model.

2.9 High Level Modeling Techniques

One recommendation for future work is to aggregate the low-level conformance indicators to a higher level. In some cases it may be appropriate to aggregate the indicators all the way to the tenet or principle that served as the top level for the hierarchical structure. In other cases, it may not be possible to aggregate the indicators any higher than one level up. In any case, a technique will be needed to model and then implement the aggregation. There are several techniques that have been developed for aggregation, two of which appear promising.

Structural Equation Modeling A method of comparing structures that has been used for over eighty years is called factor analysis. Originally developed by Karl Pearson [Pearson 01], and revised and modified by several

others such as Galton, Spearman, and Fisher [Cattell 66], factor analysis allows for both exploratory analysis and confirmatory analysis. It is linear in nature and works with the correlation matrix of the measured variables in a given system. The correlations indicate to the researcher which variables should be combined or reduced to one factor.

A class of factor analysis models is confirmatory analysis. A modeling framework that deals with causal relationships in structured systems is called Structural Equation Modeling. It is a qualitative and quantitative technique that has been used primarily by psychologists in an organizational setting. James, Mulaik, and Brett [James, Mulaik, Brett 82] wrote a short monograph that describes the basis for and the uses of Structural Equation Modeling. A very brief summary of that technique, including its assumptions, requirements, and allowable conclusions, is set forth below. This information comes from [James, Mulaik, Brett 82] and discussions with Professor Stanley Mulaik, Professor of Psychology, Georgia Institute of Technology, Atlanta, Georgia.

It must be possible to propose a theory in quantitative terms if it is to be subjected to confirmatory analysis. The process of confirmatory analysis typically begins by specifying the presumed structure of causal connections among the variables in the form of a graphic model.

Conditions for Confirmatory Analysis and Causal Inference

1. Formal statement of theory in terms of a structural model

    - Phenomena or the variables that act as causes and effects.
    - Causal connections among the variables

- A theoretical rationale for each causal hypothesis that describes the process through which a cause acts on an effect.

- Boundaries which specify the contexts within which the functional relations/equations are expected to hold

- Stability which implies that the hypothesized structure of causal connections will be consistent over specified time intervals.

2. Theoretical rationale for causal hypothesis

3. Specification of causal order

4. Specification of causal direction

5. Self-contained Functional Equations. This means that all relevant causes of the endogenous variable are included in the functional equation. A relevant cause is one that:

   - has a direct, non-minor effect on the endogenous variable
   - is stable
   - is related to the other relevant causes
   - is not linearly dependent on the other relevant causes

6. Specification of boundaries (i.e., is the functional relationship linear and additive)

7. Stability of the structural model over time

8. Operationalization of variables (i.e., at least interval level of measurement)

9. Empirical confirmation of predictions I: empirical support for functional equations

   (a) A set of predictions can be derived using the equations

   (b) A model is confirmed if the predictions regarding correlations among manifest variables are consistent with the observed correlations among manifest variables. Confirmation of predictions implies corroborative support for the structural model represented by the functional relations and equations.

10. Empirical confirmation of predictions II: fit between structural (theoretical) model and empirical data

The authors state that conditions 1, 2, and 5 are often violated by confirmatory analysis users. Condition 5, self-containment, is often violated because one or more relevant causal variables have been omitted from the study. This occurs, reportedly, because Conditions 1 and 2 were not met. These conditions deal with the development of the causal links and determining the theory behind the manifest variable that is used. It appears that most of the requirements for using Structural Equations Modeling have been satisfied through the efforts in this dissertation. The one main problem is that of linearity. If it is determined that the relationships are not linear, another technique must be found.

Artificial Neural Networks An alternative to linear techniques is Artificial Neural Networks (ANN). Artificial Neural Networks have been used for pattern recognition, clustering, prediction, time-dependent data, and speech analysis [Wasserman 89]. In the last four years many books have emerged

that cover both the techniques. the underlying principles, and the most common uses for the different forms of ANN's.

Backpropagation has been the most widely used form of ANN's. Backpropagation seems to be the most appropriate ANN in this case because its structure, hierarchical in nature, fits well into the structure proposed for doctrine. Although much of the original mathematics was first published in 1951 [Robbins and Monro 51], and some preliminary practical work occurred in the early 1960's, in the early 1980's, work by Hecht-Nielsen [Hecht-Nielsen 1988], Rumelhart & McClelland [McClelland 88], and Wasserman [Wasserman 89] showed that more complex networks that use the backpropagation algorithm could successfully solve the "exclusive or" problem as well as providing insight into pattern matching in many areas of research. If a linear relationship is the correct underlying model, the ANN will not be able to improve upon the results yielded by regression or ANOVA, which typically include a very strong linearity assumption. The strength of neural networks is their ability to organize extremely non-linear data and establish relationships between input and output, between the variables themselves, or between the dependent and independent factors [Knepell 90].

Neural networks do not utilize the same principles as regression or even clustering techniques. Instead of minimizing the distances of internal entities and maximizing the distances of external entities, Artificial Neural Networks use a logistic, non-linear aggregation method where the only distance minimized is that abstract distance between the desired output and the estimated output value. Applying Artificial Neural Networks to battle modeling, each battle has a set of output variables (dependent) which would be actual measures of success in the battle. Each battle also has a set of input variables

(independent) which are the scores of the defined measurables. The values of the variables are aggregated using a weighting scheme that is learned by the ANN (Artificial Neural Network). An approach using the sum-of-squares of the error is used to determine the overall goodness of fit of the network to the data. Since the network fit changes whenever hidden nodes in the neural network are deleted or added, a measure of fit will be applicable only to a certain configuration of the network. The configuration will be designed to model the underlying structure of doctrine as proposed in this dissertation.

The standard form for a backpropagation neural network is the following:

$$OUT_i = \frac{1}{1 + e^{\sum_{j=1}^{N} HN_j * W_j}}$$

where W_j refers to weight of the connection between Hidden Node j and the output node. HN_j is the value of Hidden Node j. N is the number of nodes in the Hidden Layer. OUT_i in the above equation is necessarily a real number bounded by zero and 1.0.

$$HN_j = \frac{1}{1 + e^{\sum_{i=1}^{V} IN_i * W_{i,j}}}$$

This is the algorithm that brings in the input variable values and aggregates them to yield the Hidden Node values. Usually the input values are normalized to avoid giving unnecessary weight to an input element that has a few large values. $W_{i,j}$ is the weight associated with IN_i and with HN_j. The algorithm can be extended to any number of hidden layers to accommodate very nonlinear models and nonconvex data. It was shown by Cybenko in

1989 [Knepell 90] that two hidden layers are sufficient to model the relationships no matter how nonconvex the data may be, as long as there are enough hidden nodes in the two layers.

Backpropagation neural networks operate using an iterative hill-climbing procedure using the gradient. A training set is normally used to teach the network the correct weights that should be assigned to each connection. The information a network contains is not a group of values for the nodes but a table of weights that indicate the importance and the direction of influence each input node or element has in achieving overall success. For battle modeling, success is defined as matching the calculated battle success scores from the network with the actual success ratings.

2.10 Measurement of Combat Power

Combat Potential is an accepted concept among combat analysts and several combat potential models have been developed [DARCOM Pam 79]. The proposals have ranged from a very simple count of available tanks in a given area to a quite complicated WEV (Weapons Effectiveness Value) [Holter 73]. The WEV was used extensively during the 1980's.

A previously used index that is currently being studied by combat modelers is the Relative Importance Index or Relative Weapon Value [Spudich 68]. It relates the target's value to the force with the weapon and the ability of that weapon to kill the target. It depends both on friendly and enemy assets and their status. Verified by empirical data, a simulation is used to calculate the relative importance of each weapon system on the battlefield. The Relative Importance Index has been tested by using it to predict the results of

battles (both training and simulated) but has not yet been accepted by the modeling community.

The one combat power unit that has emerged as dominant in the past 15 years is the Operational Lethality Index (OLI). Trevor Dupuy, the developer of this index, is a well known military historian, author, and retired combat arms Colonel. Working with the organization Historical Evaluation and Research Organization (HERO), he developed the Quantified Judgement Method of Analysis (QJMA) which used the Quantified Judgement Model (QJM) [Dupuy 85, 87]. This model and method of analysis have been examined by many military historians, analysts, and military professionals [Hawkins 93]. Dupuy worked as a quantitative military historian who developed a method of analyzing historical battles. The model seemed to work so well that it was tried for predictive purposes. The Arab-Israeli Wars of 1967 and 1973 were modeled using this method with good results [Dupuy 85]. It has been used for battles ranging from Napoleon's famous engagements to the Arab-Israeli wars of this century. The model is fairly intuitive and logically produced. The concept behind his method is to base any engagement on the basic capabilities and numbers of weapons brought to bear during the battle. He developed several measures which others have called measures of effectiveness. "We decided to try to measure the combat potentialities of opposing forces by quantifying their total weapons firepower by use of the Operational Lethality Index (OLI) concept. To this firepower we would then apply reasonable factors, consistent with historical facts and the estimates of professional military judgement, for all identifiable and presumably quantifiable combat variables." Because the two main references for this method are sometimes contradictory, I will briefly review the OLI formulas used in

this dissertation.

$$TLI_s = \sum_j RF * TPS * REL * RG * A * Reliability$$

This first formula is for a stationary, towed, or carried weapon.

The OLI for each weapon type is defined as Theoretical Lethality Index multiplied by Dispersion Factor:

$$OLI_s = TLI_s * D_i$$

As the dispersion increases, the lethality decreases. Therefore, lethality of the same weapon has decreased over the centuries as the dispersion has increased. Formally, D_i represents the number of square kilometers that typically hold 100,000 men.

$$OLI_m = (\sum_j^J OLI_s * M * r_a + P) * ROF * FC * AS * C$$

The above formula is for a mobile fighting weapon. J is the number of different weapons that are present on the mth platform. Each weapon type available on the mobile combat weapon would have its own OLI_s.

Following is a list of definitions of variables that are in one or both of the equations.

TLI_s Theoretical Lethality Index for stationary, towed, or carried weapons.

TLI_m Theoretical Lethality Index for mobile fighting weapons.

M Mobility or speed factor. $M = \sqrt{0.15} * maxroadspeed$

r_a Radius of action. $r_a = 0.08 * \sqrt{RangePerTankful}$

P Punishment factor. $P = 3000 * Weight/4 * \sqrt{2 * Weight}$ This factor estimates (empirically) the amount of punishment the mobile weapon can take and still operate effectively. The weight is given in tons.

ROF Rapidity of Fire Effect. This factor is found by entering a graph which represents an empirical function which relates the sustained hourly rate of fire to a factor which is between 0 and 1.

FC Fire Control Effect. This is a subjective number which relates the fire control effectiveness as compared to a standard weapon system, such as a M60A1 Main Battle Tank. The standard value of an M60A1 is 0.9.

AS Ammunition Supply Effect. This factor represents the ratio of the number of rounds that can be carried by a fully loaded vehicle and the number rounds theoretically fired by the weapon in one hour at a sustained rate.

C Ceiling Factor. An arbitrary, though common sense, ceiling of 30.000 feet for an aircraft was used by Dupuy. He subtracted 0.05 for every 1000 feet below 30,000 the actual ceiling was and added 0.005 for every 1000 feet above 30,000 the actual ceiling was.

RF Rate of Fire. The number of sustainable rounds that can be delivered on target in one hour. Dupuy has a graph which can be entered with the calibre of weapon to obtain an estimate of the rate of fire.

TPS Number of Potential Targets Per Strike. Accounts for added lethality of area vs. point weapons. Assume one man takes one square meter. Dupuy also supplies a table for estimating this value based upon the calibre.

RE Relative Incapacitating Effect. The probability that one hit from this weapon will result in target incapacitation.

R Range Factor. $R = 1 + \sqrt{0.001 * EffectiveRange(m)}$
For artillery and other indirect fire weapons, the calculation is: $R = 0.007 * MV * \sqrt{0.01 * caliber}$

A Accuracy. The probability that a weapon aimed exactly at the target will hit it. Strictly dependent upon the mechanics of the weapon system.

REL Reliability Factor. The probability that, for a given single use of the weapon, it will break down due to mechanical failure, or jam or otherwise malfunction.

A recent example of an institution using the Dupuy model is a feasibility study accomplished for the Secretary of Defense [Hartley 91]. This paper uses OLI and Dupuy's QJM almost exclusively to support the feasibility of forecasting relative combat effectiveness.

CHAPTER 3

Building a Model of Conformance

3.1 Overview

Chapter Three applies techniques of analysis and synthesis to model the diagnostic relationships among success in battle, prescriptive battlefield doctrine, and the actions that actually occur.

In Section 3.2, principles of representation, reviewed in Chapter Two, will be condensed into two categories – variable selection and modeling. The five principles of variable selection are:

- Applicability
- Comprehensiveness
- Parsimony
- Orthogonality
- Measurability

and the three criteria of models are:

- Parsimony
- Generalizability
- Fidelity

In Section 3.3, a hierarchical model of combat is constructed using these principles of representation. The analysis, chiefly using the principles of variable selection, leads one from the overall goal of **Victory** or **Mission Accomplishment** to a lower level representation of battle that includes the controllable variables:

- Friendly Offensive Actions
- Friendly Defensive Actions

and the uncontrollable variables:

- Resources – enemy and friendly
- Environment – neither friendly nor enemy
- Enemy Actions

Section 3.3 also develops the general concept of using prescriptive doctrine for diagnostic purposes.

In Section 3.4, we use Army Operations doctrine to guide the analytical efforts of representing friendly actions in battle. The four tenets of Army Operations are:

- Agility
- Initiative
- Depth
- Synchronization
- The recently added tenet of Versatility is not applicable.

These tenets will be used for the analysis in lieu of other taxonomies that are currently found in doctrinal literature or could be developed in this text. The result of the analysis is an architecture of current Army Operations doctrine with a clearly defined list of three measures related to Agility, three measures related to Initiative, four measures related to Depth, and four measures related to Synchronization.

In Sections 3.5 and 3.6 both analysis and synthesis are used to develop computational models which relate the measures developed in Section 3.4 to measurable, observable, friendly actions of a mechanized task force (battalion-level) while training at the National Training Center (NTC). The diagnostic measures are designed to indicate the level of doctrinal conformance for each component of Agility (Section 3.5) and Synchronization (Section 3.6). In Section 3.7 there is a summary of the 14 measures of doctrinal conformance. Section 3.8 contains the description, inputs, and calculated results of applying these measures to an illustrative example.

3.2 Method of Analysis

Rosenstein [Rosenstein 64] formalized what most modelers recognize as the modeling cycle. After identification of the system to be modeled, system vari-

ables must be identified. One selects the appropriate ones for continued use in the modeling process. The next step is to model the system by discovering relationships among variables. The variables are either inputs or outputs. The challenge is to find the best transformation of the input variable values to approximate the output variable values. If the system is a hierarchical system, the goal of the modeling effort is to find the set of variables which best models the parent concept at each level of the hierarchy.

The system being modeled is combat. The modeling effort is separated into two parts. Part One identifies the principles of variable selection that have been used successfully by systems analysts and military modelers. A simple taxonomy is synthesized from various taxonomies discussed in Section 2.8. Part Two addresses modeling criteria which are standards by which a proposed model can be measured. Rosenstein gives the name "synthesis" to this part of the modeling. The standards can be used to guide the modeling process.

After reviewing several analysts' ideas of modeling, the concepts are reduced to three criteria. Each will be discussed in terms of its capability to allow the modeler to build and evaluate models of components of doctrine.

3.2.1 Principles of Variable Selection

Section 2.7 contains the philosophy of modeling and representation from several modelers, as well as from several areas of research including psychology [Medin and Ross 92], systems engineering [Wetherbe 84], military modeling [MORS 84], mathematical modeling [Giordano 85], and data structures [Young 94]. Their works can be combined into a list of five principles for variable selection.

Applicability – The variables chosen should be relevant to the cause or purpose of the representation. There should be a tautological or a plausible cause-effect connection between a variable and the concept it purports to quantify.

Comprehensiveness – Exhaustiveness. There should be complete coverage of the concept being modeled. Comprehensiveness is determined by the purpose of the model and limited by the model's scope.

Parsimony – The smallest exhaustive set of applicable variables should be selected for use in the representation.

Orthogonality – Variables used in representing parts of a system should be as distinct as possible. An increase or decrease in one should not necessarily induce an increase or decrease in the other. Structures are more explicit and easier to understand if the representations are orthogonal.

Measurability – Each of the variables used in the model should be judged on its:

- Ease of measurement – the variable should be quantifiable and available
- Fidelity of the measurements
- Repeatability of the measurements

None of the above principles is all-important. Each must be met to a certain level or the resulting representation will not be useful. Although

there is no absolute rating or importance level for the principles, the following sequence will be used for our variable selection analysis:

- Identify applicable variables or concepts. It may not be possible to demonstrate statistically that a variable is applicable (i.e., highly correlated with observed behavior) until the model is built. (Correlation between a candidate variable and the main concept when covariance is present between the candidate variables is often misleading. Statistical correlation between variables that may have a strong but nonlinear relationship is also of little use.) Applicability may have to be determined based on doctrinal definitions or experience.

- Check the set of variables for comprehensiveness. If there is a critical part of the concept being modeled that is missing, one or more variables should be defined in order to represent it. Definitions, doctrinal and historical manuals, and experience will help in determining comprehensiveness. Such checking may lead to additional variables.

- Select the smaller set of variables if alternative sets of variables exists. the chosen set is not internally orthogonal, the second alternative set will be selected.

- Check for the orthogonality of the variables:

  - Combine or eliminate variables that represent the same concept
  - Redefine or eliminate variables that have more than one key concept within their definition

- Check for measurability. If the variable cannot be measured directly from observable data, further analysis of that variable may be necessary. Do not include those variables that cannot be directly measured or further modeled.

3.2.2 Modeling Criteria

After variable selection, modeling of the process using the selected variables must occur. Principles of good modeling or desiderata of good models are found throughout the modeling literature. Although some modelers do not differentiate between modeling and variable selection, the principles that are supported by them are easily separated. Torgerson, Young, Taylor, Giordano and Weir, and Hughes et al [MORS 84] all provide desiderata for models and modeling. These authors' taxonomies can be summarized by the following three criteria:

- Parsimony
- Generalizability
- Fidelity

Parsimony – The principle of parsimony advises that the simplest mathematical combination of variables, while still maintaining a required degree of **fidelity**, should be adopted. Parsimony, sometimes referred to as Occam's razor, allows for more manageable error assignment, smaller simulations, less sensitivity to random error, fewer computations and generally more robust models. [MORS 84]

This principle is valuable in keeping the model tractable. As stated in [MORS 84], page 84, "Beyond a point, adding detail for the sake of realism becomes self-defeating." As variables are added to improve fidelity and comprehensiveness, the complexity of the model is increased. The intuitive nature of the model often decreases, as does the ability to test the model. Paradoxically, as the complexity increases, the unknown complex interactions between variables sometimes cause the fidelity actually to decrease – negating the purpose of adding the variable. If the addition of a variable does not significantly improve the performance of the model, then the modeler should not add that variable. Specifically, in the case of modeling measures of conformance to doctrine, an additional component will only be added if it significantly improves the model's ability to accurately represent a unit's conformance to doctrine. During analysis, it may not be possible to determine statistical significance of an additional component. In these cases, the modeler will have to rely on *expected* improvement in the model's fidelity.

A variable may be valuable at a lower level of modeling, such as at the individual or squad level, but not important at all at a higher level such as battalion or brigade. Parsimony and fidelity are supported by not adding this variable. If a model is already constrained due to the data available or the physical limitations of the variables being used, it is not valuable to introduce a new term which may improve the fidelity of the model in a region that cannot be evaluated. Parsimony would be violated by the addition of such a term.

Generalizability – Robustness. A generalizable military model is not too restricted to specific terrain, unit type, weather or other common battlefield variables.

This principle is important to the usefulness of the model. For example, a model may be so specific that the conformance to doctrine can be consistently measured only for:

1) A mechanized infantry battalion

2) An offensive posture

3) A deliberate attack

4) Night operations

5) 90

6) Clear skies

7) Relatively flat terrain

This model may rate high in fidelity in this very specific situation. and be quite useless for any other unit that differed from those conditions. The model being designed to measure the conformance of a unit's actions to doctrine should be general enough to be useful to all maneuver battalions, in most types of weather and terrain, in a defensive or offensive posture, and with a variety of weapon systems available. If the addition to or a modification of a given model increases fidelity but violates one of these guidelines for generalization, it will not be used.

Fidelity – The degree of closeness of a model's predictions or results to reality.

There are two faces to fidelity, analytical and empirical. During the analysis and synthesis phases, analytical fidelity will be adhered to through use of definitions, logic, doctrinal publications, and tactical knowledge. In the testing phase, empirical fidelity will be evaluated by the model's proximity to the conformance values assigned by experts. If two models have the same fidelity, the more parsimonious one will be used. Similarly, if two models are equal in fidelity, the more generalizable model will be used. Other things being equal, the model with the highest empirical and analytical fidelity will be selected.

3.3 A High-Level Model of Combat

3.3.1 Representing Victory in Battle

Figure 3.1 depicts the influences that affect a commander's decisions and the major factors of the outcome of a battle. After the commander has considered perceptions of the environment, the mission, the doctrine, the enemy's probable actions, and the resources available to both the friendly and enemy forces, he must choose a course of action (COA). The only influence his decision has on the outcome of the battle is the effect on the factor of friendly actions. Five other very important elements that affect the battle outcome are friendly and enemy resources, enemy actions, the environment, and whether the friendly force is on the offense or the defense. Any model of victory in battle must include these factors.

Although Figure 3.1 shows which factors affect the commander's decision and which factors affect the outcome of the battle, it is not clear how these factors affect each other. A factor only may affect all other factors, only

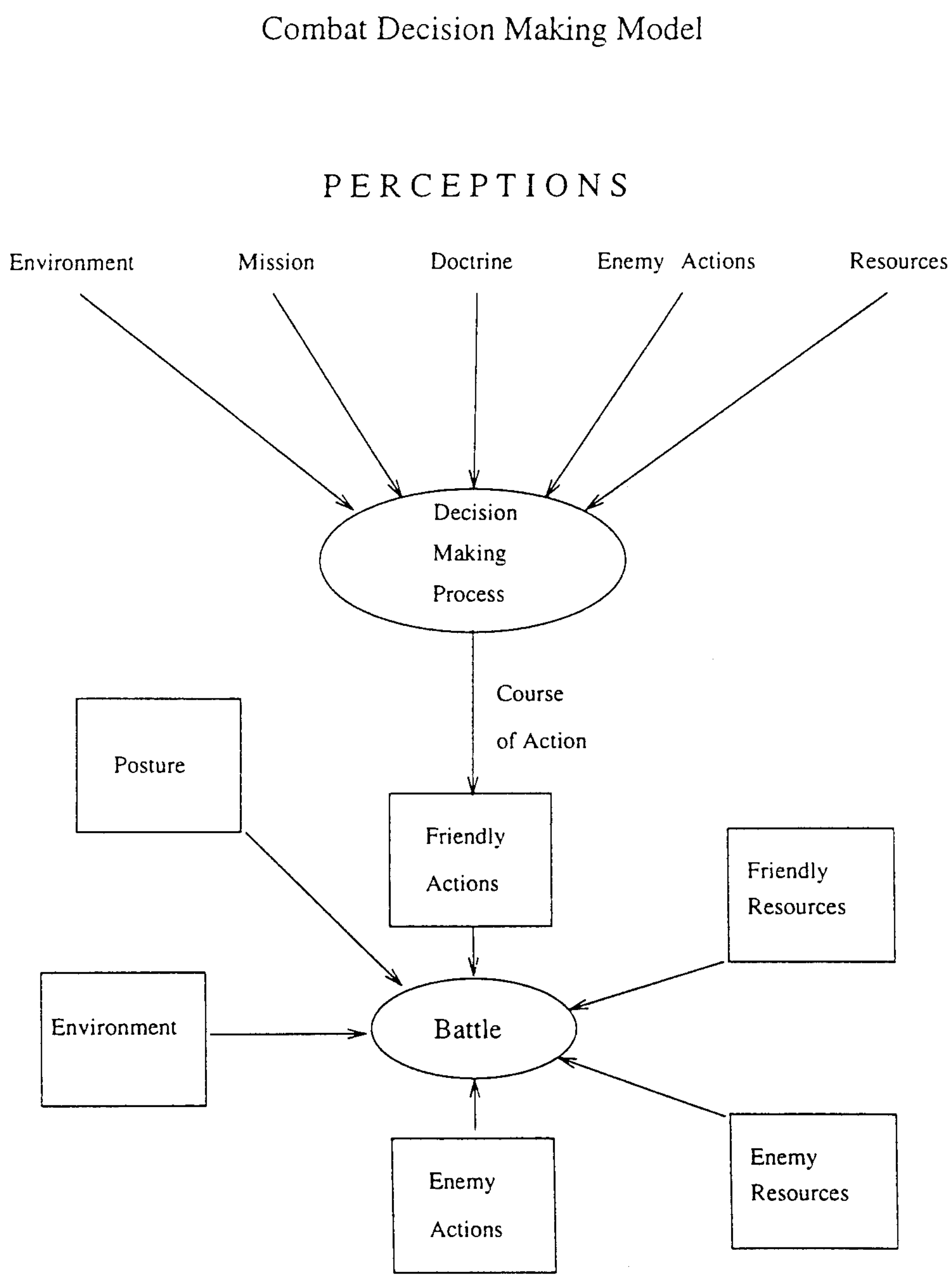


Figure 3.1: The Relevant Factors of a Battle

one other factor or none. A more structured model of the relationships among these factors should help the commander make a more intelligent and accurate decision as to the proper course of action for his forces.

In the past, one of the most successful and insightful means of representing relationships among elements in a system has been through a hierarchy. Hierarchies have been used to describe systems as diverse as classifying living organisms, describing the human learning process, structuring the job assignments in a factory, and analyzing tasks and subtasks of workers on an assembly line. Complicated networks are normally easier to understand if they can be represented by a hierarchy. Hierarchical models are also favored in organization of philosophical concepts (e.g. Plato, Aristotle, and Kant). The theory of 'divide and conquer' is the motivation behind most uses of hierarchy. A complicated system of interactions is difficult to understand. By separating the system into smaller, orthogonal parts, each subsystem can be attacked separately. Often, the concepts at the bottom of the hierarchy are simple enough to be modeled and understood.

At the top of the hierarchy of the system of combat is victory. At the bottom of the hierarchy are all of the battlefield actions. Through analysis we will build a hierarchy which will allow commanders to see the relationship between battlefield behavior and victory.

From Figure 3.1 we have six types of factors that affect the battle outcome.

- Friendly Actions
- Friendly Resources
- Enemy Actions

- Enemy Resources
- Environment
- Posture of Friendly Forces

Considering the above groups of factors, the following statements are presented as assertions:

1. **Offensive** battle is intrinsically different from **Defensive** battle.
2. For purposes of attaining a friendly victory, **Friendly** is different from **Enemy**. They represent two distinct sides of a two-sided competition.
3. **Actions, Resources**, and the **Environment** are different from each other. The intersections of these sets are empty. The union of these sets contains everything that affects the outcome of a battle.

The three assertions above separate the factors affecting combat into three distinct groups. Using a hierarchical structure as a framework, the three sets of mutually exclusive, collectively exhaustive categories can form total of six (3!) hierarchical configurations where each set represents a single level in the hierarchy. Figures 3.2, 3.3, and 3.4 show all the possible ways of constructing the hierarchy using the three sets. In the following discussion, five of the possible structures will be eliminated to leave one hierarchy which will be used throughout the remainder of this research.

The doctrinal hierarchy will be built using the analysis techniques described in Section 3.2. Starting from victory or mission accomplishment, a mutually exclusive (orthogonal) set of categories must be found that are applicable to victory in battle, comprehensive, parsimonious, and measurable. The six candidate hierarchies will be evaluated based upon these principles.

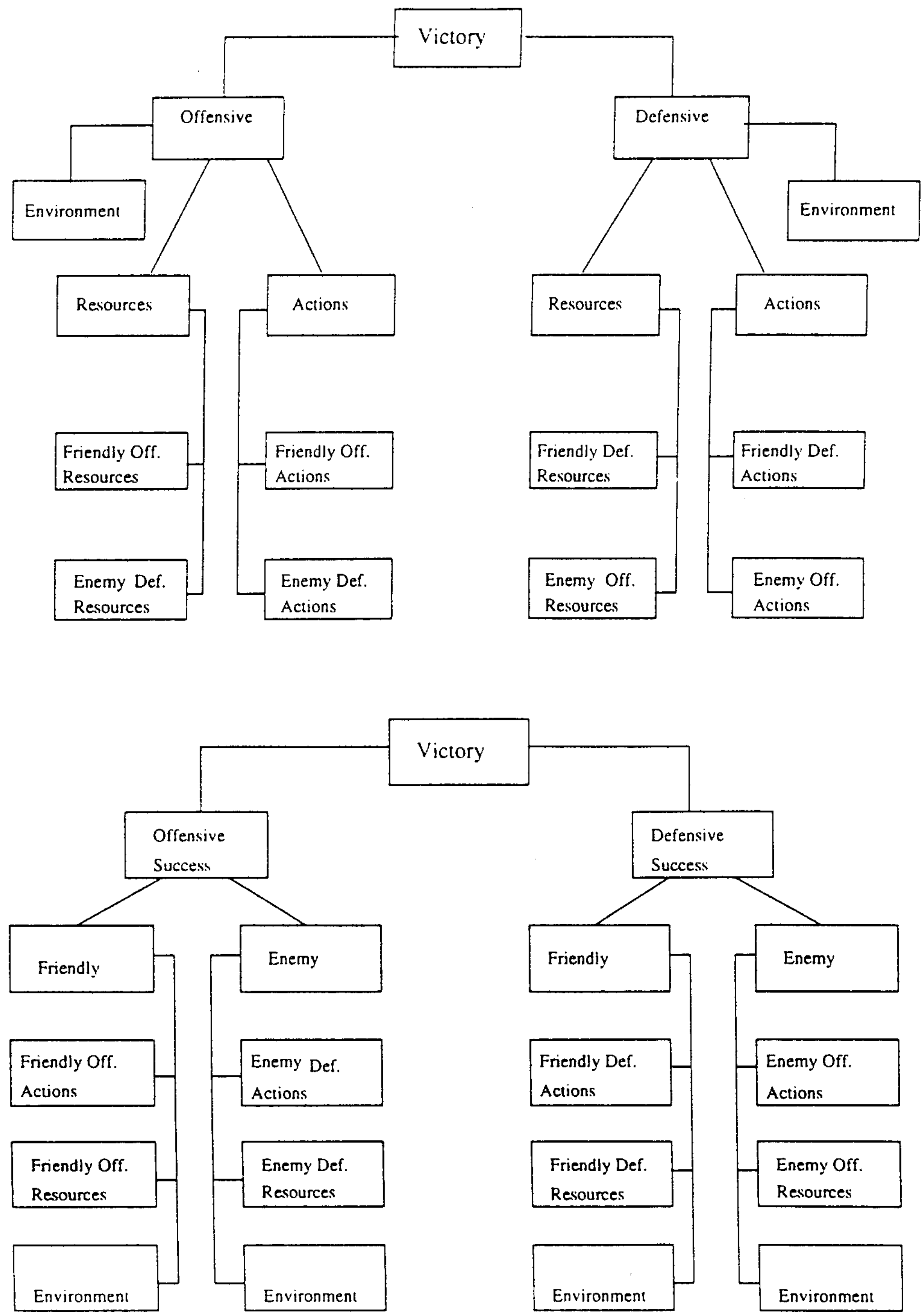


Figure 3.2: Alternatives 1 (Top) and 2 (Bottom)

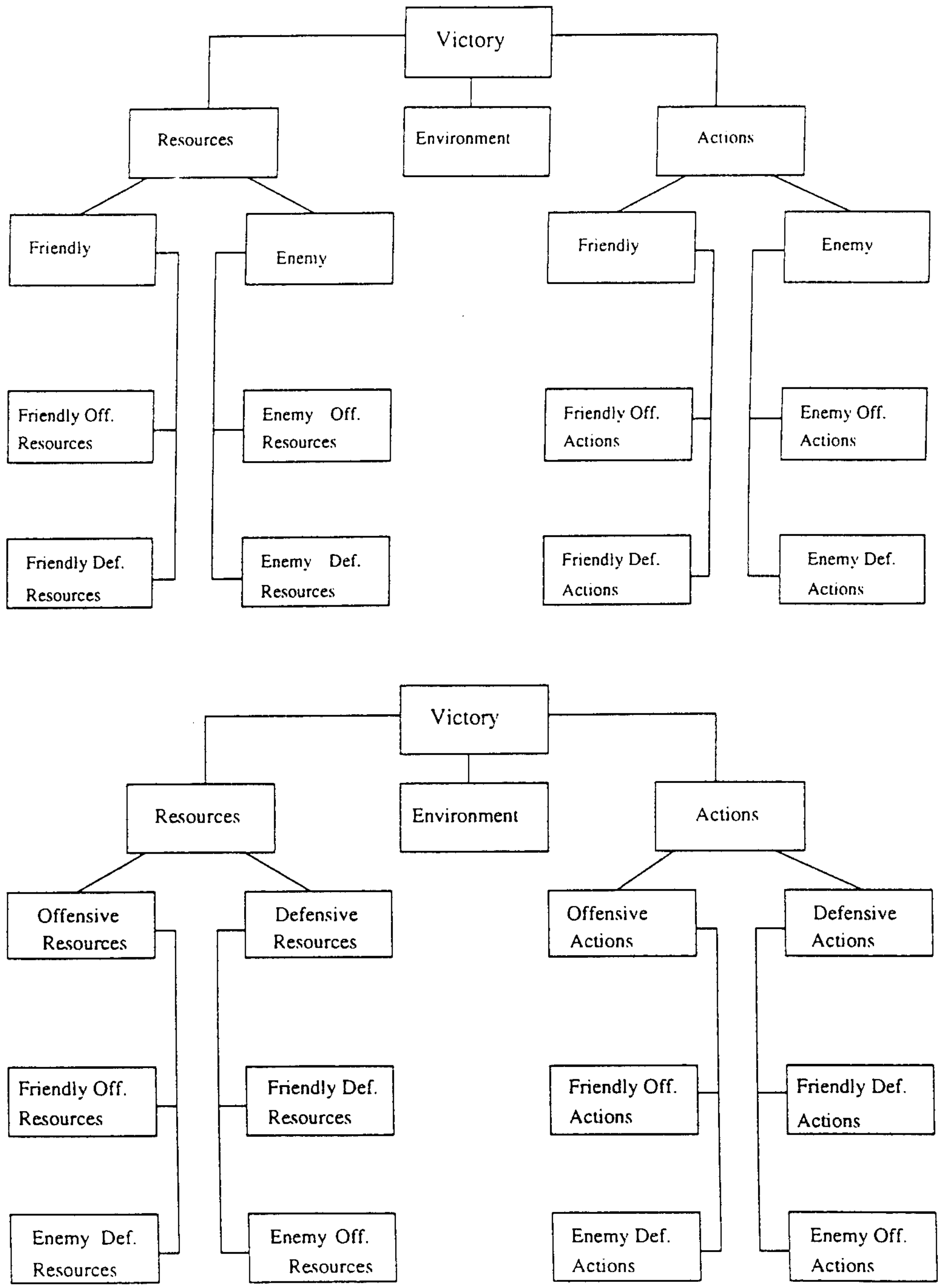
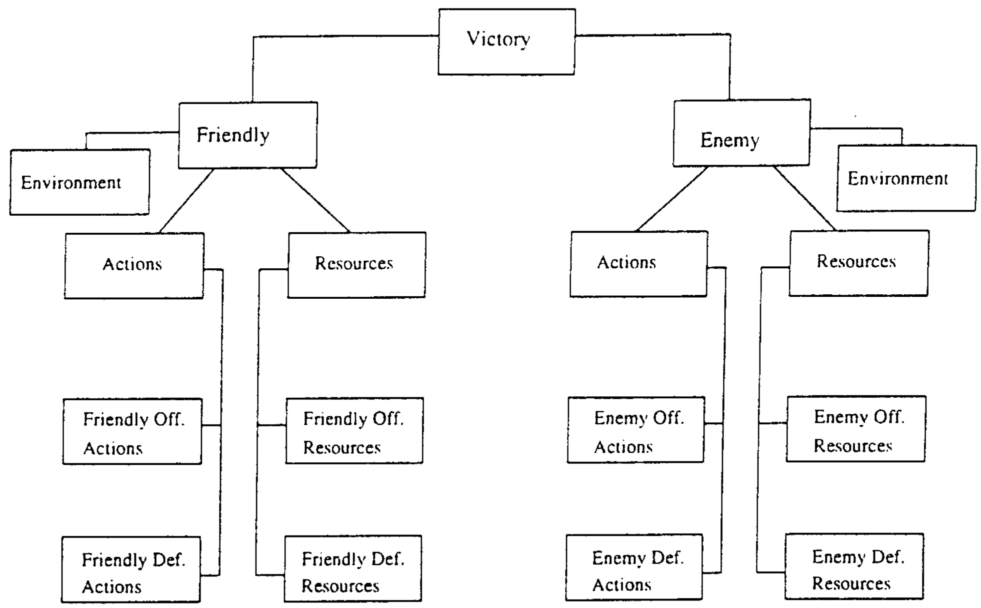


Figure 3.3: Alternatives 3 (Top) and 4 (Bottom)



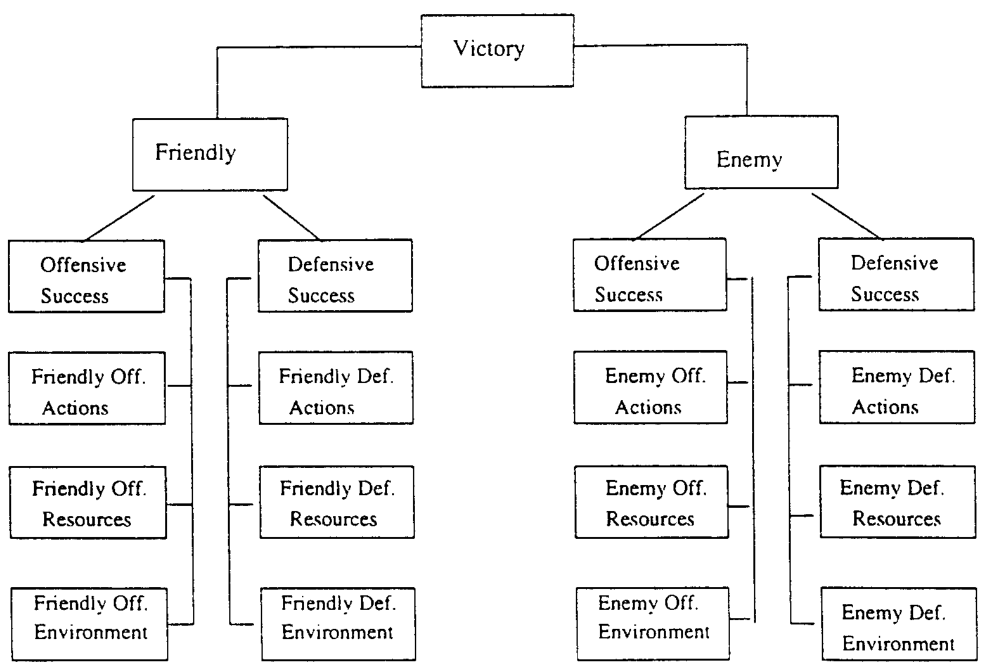


Figure 3.4: Alternatives 5 (Top) and 6 (Bottom)

The two categories in Statement 1, offense and defense, are comprehensive categories with respect to victory. However, these same two categories are not comprehensive with respect to the environment since the environment is neither offensive or defensive. Offensive and defensive are not orthogonal in categorizing resources. Many resources are both offensive and defensive. For these reasons, it does not appear that Alternatives 4 and 5 should be considered as viable.

The categories in Statement 2, friendly and enemy, are exhaustive when categorizing actions that take place in a battle or resources that are available for a battle. The environment is usually not considered friendly or enemy. If friendly and enemy were used to analyze victory in battle, they would be factors rather than categories. Certainly a battle cannot be categorized as either friendly or enemy since both participate. Both have a profound effect upon the outcome which would support the applicability of their use at this level. Since battle is the hostile interaction of these two sides, it may not make sense to separate them so high in the hierarchy. All analysis from this level would have to address either the enemy or friendly force, with little or no interaction between them. If friendly and enemy are at the top of the hierarchy, either offense and defense or the set of actions, resources, and environment must follow. However, since Alternative 5 has already been eliminated, then actions, resources, and environment have also been eliminated as candidates under friendly and enemy. Referring to Alternative 6, under the friendly category are the categories of offense and defense. Certainly a friendly force must be either on the offense or defense. However, offensive success is now limited to the factors of friendly offensive actions, friendly offensive resources, and the environment. Comprehensiveness has been violated here since friendly

offensive success depends upon all of the factors shown in Figure 3.1. The hierarchy in Alternative 6 does not allow all of the applicable factors and therefore should be omitted from consideration.

Alternative 3, which places the factors of actions, resources, and environment as the proper breakdown of victory, proposes to separate each of these categories into friendly and enemy components. Such an analysis seems to work. Friendly and enemy is a natural, mutually exclusive, and comprehensive categorization of both actions and resources. Finally, friendly resources are decomposed into friendly offensive and friendly defensive resources. This is also a mutually exclusive and comprehensive decomposition.

The Alternative 3 hierarchy appears to be well suited to structuring a battlefield system for a war or an extended campaign. The total resources for the friendly side are balanced against the total resources for the enemy side. Similarly, the total actions, offensive and defensive, are combined for the friendly side and compared to the combined enemy actions to arrive at a representation of the actions during the war. However, in a single battle, one cannot combine the defensive and offensive resources and compare them with the same from the other side. In any given battle, only one type of resource is important and usually one type of action is important.

Because the offense and defense are combined so far down in the hierarchy, the distinction between the two postures is lost and the important interaction between the two sides, given the posture, is also lost. For example, if a battalion has recently acquired very fast, and accurate tanks, but has not yet been issued the capability to dig-in and protect itself defensively, the results of the battle will depend significantly upon the posture. This discrepancy is lost as soon as the bottom elements in the hierarchy are aggregated. Therefore,

for representing victory in a single battle, Alternative 3 would have to be eliminated, unless no other alternative is available.

Alternatives 1 and 2 place offense and defense as categories of victory. Certainly all victories must be either offensive or defensive in nature, thereby satisfying comprehensiveness. Orthogonality has already been established for these categories. The options left are whether to decompose offense (and defense) into actions, resources, and the environment or to first use the factors of friendly and enemy.

Because we want to avoid separating enemy and friendly too early in the hierarchy, Alternative 1 appears to be the most favorable. In Alternative 2, friendly offensive actions are combined with friendly offensive resources and the environmental effect. The 'friendly offensive' concept would combine with the 'enemy defensive' concept to predict the chances of offensive victory. At this point we must determine whether it is preferable to have a total friendly vs. a total enemy comparison, or to compare enemy defensive (depending upon posture) resources against friendly offensive resources and enemy defensive actions against friendly offensive actions. Both alternatives satisfy the comprehensiveness principle as well as the orthogonality principle. Alternative 1, by allowing the appropriate resources to be compared separately from the actions, is more applicable to the main goal of victory.

Proposed Categories of Victory in Battle

Alternative 1 will now be analyzed completely using the five principles of category (or factor) selection.

Because the relationships between factors differ significantly between postures, it is reasonable to categorize posture before trying to represent it. The

proposed categories breakdown victory into:

- Offense
- Defense

Selection Criteria

Applicability Applicability demands relevance to the purpose of the model. The purpose of our model is to find indicators that will help commanders improve their chances of victory. If a model of victory differs substantially depending upon the category of battle being fought, then the set of variables that must be submodeled is the set of types of victory that are expected to have substantially different models – Offensive and Defensive Victory. The discussion above related some of the well-known differences in actions. resources, and environmental effects. The Army Operations manual discusses tactics, ammunition supply, positioning, and mobility requirements all differently for offensive and defensive operations.

Comprehensiveness Certainly, either offensive victory or defensive victory must occur to attain victory. Jomini identifies all battles as either offensive, defensive, or battles fought unexpectedly.[Jomini 1838] Unexpected battles quickly turn into either hasty offensive or hasty defensive battles. Clausewitz states in Book One, Para 17 [Clausewitz 32],"...there are two distinct forms of action in war: attack and defense." Doctrinally, current manuals address tactics separated into offense, defense, and actions other than war. This research will not address the doctrine of operations other

than war (OOTW). Omitting OOTW, historically and doctrinally the two categories of offense and defense are comprehensive.

Parsimony Because the posture affects the relationships between the other factors so broadly, parsimony can best be served by developing separate models for offense and defense rather than trying to account for the differences in posture in every discussion of every factor throughout the rest of the modeling life cycle. Such a separation will simplify the models lower in the structure.

Orthogonality Orthogonality is met by this categorization and is supported doctrinally, historically, and empirically. This separation appears to be a natural one based upon the completely different goals of the forces in the two different postures. As Clausewitz stated in Book Six, "Defense has a passive purpose: *preservation*; and attack (offense) a positive one: *conquest.*" [Clausewitz 32]

Empirical support for such a separation is easy to find. All of the databases for the thousands of battles that have been fought in the last 13 years at the NTC are named by the mission type which is either offensive (attack, hasty attack, movement to contact) or defensive (deliberate defense, hasty defense, defense in sector). The extensive database used by Dupuy in his development of the HERO model of battle describes the battles from which they were obtained first by their posture; i.e., offense or defense, and then by other critical elements.[Dupuy 85]

The great writers of military theory have also implied their support of orthogonality of offensive and defensive efforts. Jomini, a well-known contemporary of Clausewitz, wrote, "There are three types of battles ... Offensive

battles ... Defensive battles ... and battles fought unexpectedly...".[Jomini 1838] Clausewitz dedicated two separate books on defense and attack (offense) revealing his support of the orthogonality of the two concepts.[Clausewitz 32] Although these two theorists/philosophers differed on several issues, both Jomini and Clausewitz divided most of their doctrinal writings into these two categories.

Past and current doctrinal manuals of the U.S. Army support the unambiguous distinction between the two postures. When commanders brief their soldiers, using the five-paragraph operations order, the mission predictably begins with the words 'attack' or 'defend.'

Measurability Measurability is the last principle against which this analysis of victory must be evaluated. Unfortunately, offensive victory and defensive victory in battle are as enigmatic as the original goal of victory in battle. Even though the results of battles have been continuously analyzed, there is still a problem establishing diagnostics usable by the commander. Further decomposition and modeling may produce the desired diagnostic results.

3.3.2 Offensive and Defensive Victory

Proposed Decomposition of Offense and Defense

Several sets of variables are proposed as feasible for representing Offensive Victory. The third level of the proposed hierarchy consists of:

1. Resources
2. Actions
3. Environment

Applicability Resources have high applicability to this model because they are an important factor in the outcome of any battle. Many combat models, based either on Lanchester Equations or Markov Chains [ORSA 92] focus on opposing forces' resources. Even though these models range from the deterministic to the stochastic, the resources are key. Force ratio is a simple and popular way to predict outcomes of battles. Dupuy, one of the more complex of the modern modelers, considers resources, including personnel, weapon systems, and vehicles, as the element that carries the most weight in predicting victory [Dupuy 85].

Using battlefield actions to model combat and predict outcomes has a different history than that of resources. Tacticians believe that, given the resources available, the actions taken during battle are critical. Doctrine, especially in the last 100 years, gives as much importance to actions taken during the battle as it does to having the resources available. Historically, the importance of actions has been established by a variety of books by authors ranging from Clausewitz to Jomini to Bretnor to Depuy. U.S. Army leaders are trained to believe in the critical value of action during battle. The reviews of training battles conducted at the Combat Training Centers (CTCs) focus almost entirely on actions taken and decisions made rather than on what resources were available and how they performed. Intuitively, historically, and currently in training, there is support for the applicability of actions during battle.

The environment has already been shown to be applicable. Dupuy states, "Environmental variables include weather, terrain, and season. Commanders have no influence over this kind of variable, and they affect both sides ..." [Dupuy 87].

Comprehensiveness The resource concept includes such elements as personnel, training level, equipment, weapons' characteristics, and ammunition. Actions include planning, reacting, moving, firing, and decision-making. The environment includes the tactical situation, weather, terrain, climate, political situation and other unknown factors. Given the umbrella-like coverage of the concept of environment, it is almost tautological to state that the three concepts are comprehensive.

Parsimony Whereas parsimony requires that we examine all three concepts to check for overlap or redundancy, to select areas more general would violate both the applicability and the orthogonality principles. Given the situation to be modeled, the only categories at this level that would be more parsimonious would be friendly and enemy. This argument has alreadv been discussed and friendly and enemy would not be appropriate.

Orthogonality To use this representation we must meet the orthogonality principle. Intuitively, resources are quite distinct from actions. Upon entering battle, resources are fixed but actions are still being planned, coordinated, and executed. Actions involve motion and decisions whereas resources are 'things' that can be used up, destroyed, or replaced. Resources can be increased or decreased without *causing* a change in actions. Actions on the battlefield can often be changed, modified, or stopped without significantly changing the resources. This indicates an orthogonal relationship. Because resources and actions are both so elemental for offensive success, they certainly have an effect upon each other as the plans made for battle must consider both actions and resources. However, they are certainly dif-

ferent concepts and represent two distinct variables of battle. **Resources, actions** and **environment** satisfy the principle of orthogonality. Using this set of variables should allow the enemy – friendly interaction to be delayed through one more step of analysis, increasing the realism and increasing the orthogonality at the lower level.

Measurability Resources both constrain and support battlefield actions. Combat analysts have been quite successful at measuring resources. The quantity, type, and quality of personnel, equipment, supplies, and expertise are known and tracked both in combat training exercises and during actual battle [Gulf War 91] [Ravid 91] [Schwartzkopf 92]. While theorists, tacticians and historians have discussed at length tactical actions and their effect upon the outcome of the battle, combat analysts have not emphasized the *measuring* of actions to assist them in model building and outcome prediction. Several exceptions include recent work on measuring actions pertaining to the tenet of synchronization. [Lamont 92] [Dryer 89] [Dryer 91] [Kemple and Larson 93] The large difference in the type and quantity of analytical work in these two areas also demonstrates the distinction that exists in the minds of the analysts, supporting orthogonality.

Symmetry Between Offense and Defense

There is no conceptual difference between offensive victory and defensive victory that would change the variables needed for good representation. Obviously the relationship between these variables is radically different and different parameter values would be expected for a mathematical model of the two postures. Because of assumption of similar variables, it is proposed

that defensive victory can also be decomposed into resources, actions, and the environment.

3.3.3 Analyzing Resources, Actions, and Environment

Resources

The resources that can affect chances of offensive victory can be represented in several ways.

1. Battlefield Operating Systems:
   - Maneuver
   - Fire Support
   - Air Defense
   - Battle Command
   - Intelligence
   - Logistics
   - Mobility, Counter Mobility, and Survivability
2. A more general classification:
   - Personnel
   - Fighting Systems
   - C3I – Command, Control, Communications, and Intelligence Systems
   - Logistics

3. A still more general classification:

    - Combat Arms
    - Combat Support
    - Combat Service Support

4. The most general classification:

    - Enemy Defensive Resources
    - Friendly Offensive Resources

Proposed Variables All of these classifications are applicable and comprehensive (not discussed here) in that they cover every significant resource that could affect victory. Each of the variables of the first three sets of variables must eventually be separated into friendly and enemy resources. Therefore, for the concept of resources that apply to offensive victory, the following variables are proposed:

- Friendly Offensive Resources
- Enemy Defensive Resources

Variable Selection Criteria

Applicability The enemy and friendly separation that was applicable in the analysis of Offensive Victory is still valid.

Comprehensiveness This has been discussed and supported previously. Any resources that will affect the outcome of the battle must either be friendly or enemy. A resource cannot be both friendly and enemy and if it is neither, it is not considered a resource. Captured resources are not considered.

Parsimony There is no more parsimonious method of analyzing the resources in a battle. Parsimony was not even an issue in the discussion for offensive victory when actions were included.

Orthogonality The argument that kept enemy and friendly categories from being used higher in the hierarchy is not valid at this level. There is no reason to group Air Defense Enemy systems with Air Defense Friendly systems since they do not target each other or even interact with each other. Similar statements can be made about Combat Service Support systems of the opposing forces. All of one force's resources work together. A weakness in one area, such as Air Defense, may be made up by another such as maintaining air superiority. Poor logistics support may be countered by quick and bold offensive action followed by a lag that allows the logistics portion of the force to catch up. There is some interaction between the friendly armor resources and the enemy armor resources which decrease the orthogonality. However, it was admitted that there will always be some violation of orthogonality with respect to friendly and enemy interaction due to the nature of battle. This violation appears to be small at this point of the analysis. The orthogonality principle is considered adequately satisfied.

Uncontrollable Resources Resources, even though they are a significant factor in the outcome of a battle, are generally not controllable by the lower level commander. A brigade, division, or even corps commander usually controls the assets available to a battalion commander. The enemy resources are certainly not controllable by a battalion commander. except indirectly through attrition. A factor that is not controllable is not instrumental for diagnostic purposes except as a normalizing factor or a blocking factor for the experiment. Therefore, the enemy and friendly categories of resources will not be further decomposed or modeled.

Actions for Offensive Victory

Proposed Variables Actions that affect offensive victory could be categorized in much the same manner as the resources. The following decomposition is proposed to represent actions relevant to Friendly Offensive Victory:

- Friendly Offensive Actions
- Enemy Defensive Actions

Applicability Applicability and relevance to the purpose of the model will help determine which representation is most appropriate and best suited for diagnostics – the purpose of the model. The feedback that this model will yield will help the commander decide what plans to make and subsequently, from Figure 3.1, what friendly actions should occur. A friendly commander cannot actually control the actions of the enemy. He can merely control the friendly actions and, by so doing, create a situation in which the enemy actions will favor friendly offensive victory. Therefore. the most effective

diagnostics will be the ones that focus on friendly actions and their effect upon the outcome of the battle. The principle of applicability causes the selection of **friendly offensive actions** and **enemy defensive actions** as the variables to represent actions under offensive victory.

Comprehensiveness There should be no doubt as to the comprehensiveness of the two categories relevant to Actions for Offensive Victory.

Parsimony A minimum number of variables are used. They allow the modeling that will occur to omit friendly – enemy interactions.

Orthogonality Although they interact and depend on each other, friendly offensive actions and enemy defensive actions are orthogonal in the sense adopted for this work (see Section 3.2.1), because they are distinct and are tied together only through the decisions that the model exists to support. Each commander acts or reacts on the basis of perceptions shown in Figure 3.1, including:

- Environment
- Mission
- Doctrine
- Enemy Actions
- Resources

These perceptions are combined with experience and decision-making process to arrive at a course of action. Thus, the enemy actions, or perceptions

of them, can be viewed as inputs to the situation. The situation constantly changes in a combat environment and friendly actions are the only controllable part. Diagnostically, the model can progress no further until the situation, including enemy actions, has been removed leaving only friendly actions.

Many elements of friendly actions and enemy actions are orthogonal such as initial positioning, a planned course of action, distribution of ammunition, rate of advance before contact, actions of reconstitution, reserve activities, intelligence gathering, preparation of positions, and many more too numerous to list. The nonorthogonal parts of the actions to be modeled will be analyzed for orthogonal subelements or will be normalized by measured actions of the enemy. A continued effort will be made to retain orthogonality for simplicity, comprehensibility, and objectivity.

Measurability Measurability is needed only for those variables that support the purpose of the model. Enemy actions will not be measured or modeled except for normalization or for possible comparison measures needed for modeling friendly actions. Measuring both friendly offensive and defensive actions will be the topic of the next section.

Environment

The environment is a variable that is easily decomposed into orthogonal elements, some of which are also measurable. The military has been accomplishing such a decomposition for years. Doctrinally, the environment is represented by:

- Weather

- Geography or Terrain
- Climate
- Vegetation
- Political Situation
- Unknown Factors

These are the variables that have been found to be important and significant in their effect upon the outcome of a battle by military historians and practicing generals [Dupuy 85].

Since none of these categories is controllable, they are not useful in developing diagnostics, except as modifiers or classifiers. The scope of this modeling effort does not include modeling uncontrollable factors. Identifying them will be useful during the experimental design phase because of their acknowledged affect upon the outcome of battle. The principles of analysis will not be evaluated for the environment's components.

Similar Results for Defensive Victory

Reference Figure 3.1, wherein defensive victory is also separated into resources, actions, and the environment. Similarly, the environment for defensive victory will be represented by the same variables.

The resources will be decomposed into **enemy offensive resources** and **friendly defensive resources**. Finally, and with similar reasoning, actions under defensive victory will be represented by **enemy offensive actions** and **friendly defensive actions**.

Figure 3.5 is a graphic representation of the results of this analysis.

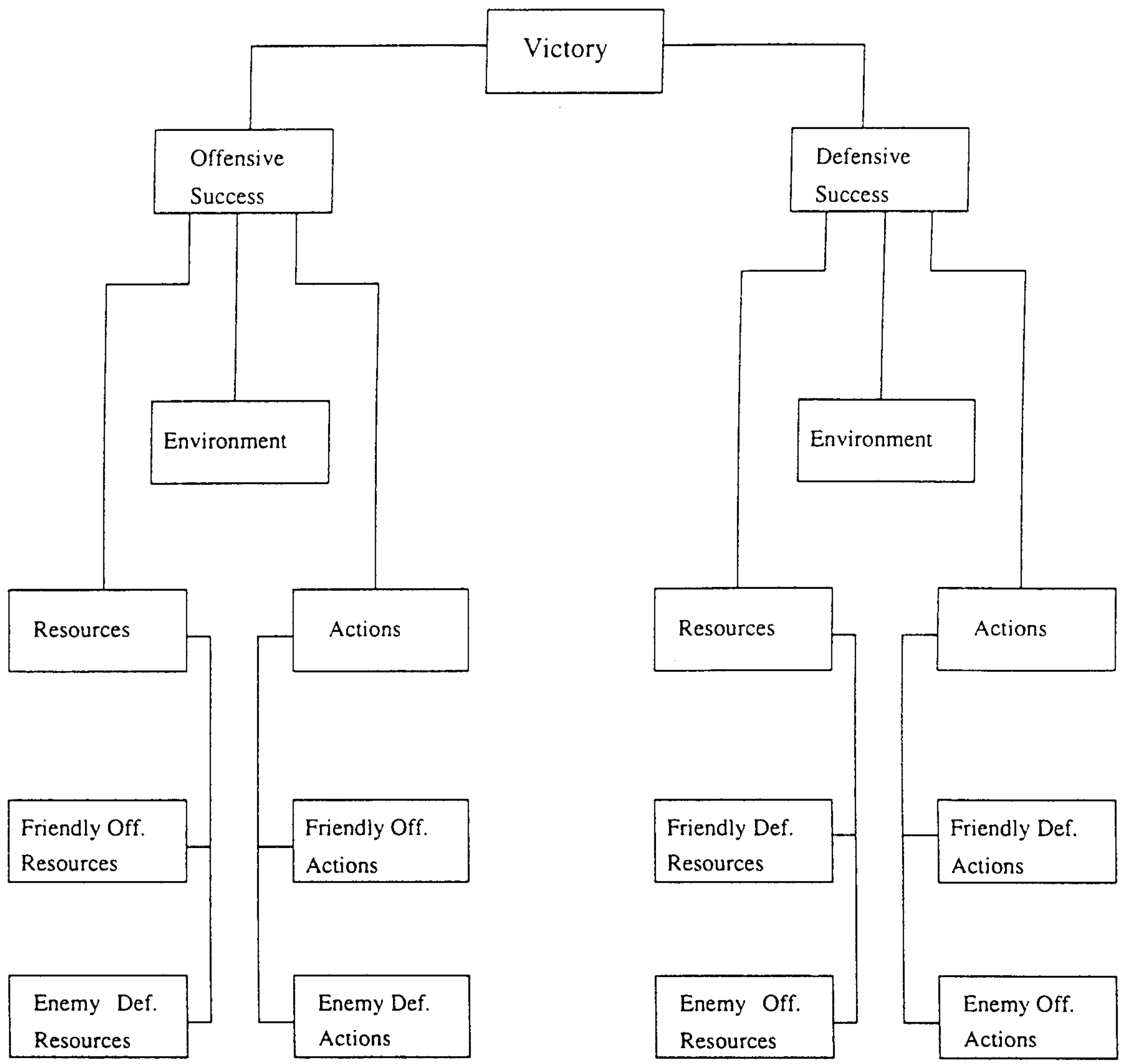


Figure 3.5: Diagram of the high-level structure of battlefield analysis.

3.3.4 Doctrine as the Key to Friendly Actions

As stated in Section 1.8, the scope of research is limited to a battalion-level mechanized task force performing defensive and offensive operations. The friendly battalion commander controls either friendly offensive actions or friendly defensive actions, depending upon the posture and the mission. The remainder of this text will focus upon the control of friendly actions through diagnostic measures, and how this control can be the commander's tool for increasing his influence over the outcome of the battle.

The Army Operations manual [FM 100-5 93] states on page 1-1 that doctrine is authoritative, meaning that combat units and their leaders are to fight using the guidelines and rules of doctrine. Doctrine was established so that leaders do not have to learn from pure experience or by trial and error. Leaders are taught that they maximize their chances of victory in battle by following doctrine. Diagnostically, the results of a battle are difficult to use due to the confounded effects of not only friendly actions but the environment, friendly and enemy resources, enemy actions, as well as unknown or immeasurable factors (refer to Figure 1.1). If, however, it is assumed that following or conforming to doctrine will improve the chances for victory, regardless of the other factors just named, the difficulty of developing diagnostics decreases. One must measure a unit's actions' conformance to doctrine based upon the principles of doctrine and the observable actions of the fighting force.

3.4 Developing Diagnostic Measures of Friendly Actions

3.4.1 Doctrine as a Guide for Development

The principles of representation require variables that are applicable and measurable. In Chapter 1, the four tenets of Army Operations doctrine were chosen as most representative of current Army doctrine and as the foundation of the documents that espouse the doctrine. Table 3.1 shows the leading alternative doctrinal organizations for combat.

The tenets were created as short, easy to remember, intuitive, and motivating concepts. Over the past 12 years, four of the five tenets of Army Operations (i.e., tenets of Airland Battle) have been tested in training, in theory, and in combat. None of these tenets has been removed from the manuals. One tenet, versatility, was recently added when the world situation demanded a force that was versatile enough to accomplish many different missions including peacemaking, peacekeeping, and humanitarian aid; it has more to do with resources than with battlefield actions and is not of interest in modeling conformance to doctrine. The baptism by fire received by the other four tenets has strengthened their acceptance in the U.S. Army community and makes them the lead alternative for organizing battlefield behavior.

The analysis will begin with the assumption that the tenets are an appropriate representation of current doctrine. This section will continue to use the principles of variable selection and modeling to organize the identifying, classifying, and measuring of friendly actions with respect to the four tenets of Army Operations.

Table 3.1: Four Doctrinal Taxonomies

Taxonomy	Number of Categories	First Used	Acceptance
Tenets of Airland Battle	4	1982	Accepted by most as simple and intuitive. In FM 100-5 and FM 100-1. Stressed at Combat Training Centers.
Principles of War	9	1921	Accepted then relegated to checklist. Reappeared in 1982 in FM 100-1 and stressed in FM 100-5 in 1993.
Imperatives of Airland Battle	10	1982	Described as prescriptive operating requirements. more specific guidance than the tenets. Omitted from current doctrinal manuals.
Dynamics of Combat Power	4	1986	Retained in current FM 100-5 but not stressed in teaching or training. Only taxonomy to contain leadership.

3.4.2 Components of Agility

The prescriptive nature of the tenets implies that commanders and units should be as agile as possible. Agility means being able to marshal forces in sufficient numbers and combat power to take advantage of both enemy vulnerabilities and available key terrain. This description of agility mixes friendly and enemy combat power and friendly and enemy speed. It also relates friendly actions to enemy vulnerabilities. All of these relationships are impossible to represent in a parsimonious and orthogonal manner. The following is offered as a more usable definition of agility: *The ability to act or react quickly with as much force as possible.* The essential meaning of agility has been kept but now there are absolutes that can be prescribed and measured. It is important to note that in its dictionary meaning agility is a *capability*, whereas our aim is to characterize not capability but *behavior.* Our modeling effort is focused on friendly actions (behaviors), not capabilities (resources). We will represent and finally measure how much agility of a unit is expressed by its behavior during battle.

Proposed Components

The following components of agility are proposed.

Mental Agility is the ability of a commander to make quick decisions about the course of action that the unit will take.

Organizational Agility is the ability to act and react quickly, within an organization, to changing missions and changing battlefield conditions.

Physical Agility is the ability to move combat power on the battlefield.

Component Selection Criteria

Applicability The applicability of these components is first supported doctrinally in the Operations Manual [FM 100-5 93], pp. 6-15, where it states. "Original plans may require modification as the enemy situation changes or becomes clear. Tactical formations, therefore, must be able to modify their direction of movement or orientation of defenses during operations. The *mental agility* of the commander, *organizational agility* of his staff, and *physical agility* of his units are vital to success." An examination of the definition of agility lends support to the separation of agility into the three areas listed above. The "ability to act and react quickly with as much force as possible" obviously supports the idea of physical agility. Reacting involves more than physical agility, more than a quick movement of forces. It involves a time-sensitive evaluation of the alternatives and a decision, exactly the meaning of mental agility. Organizational agility allows the decision-maker to have multiple alternatives available when the decision presents itself. It also allows the commander to translate mental agility into physical agility by publishing and disseminating the orders.

Comprehensiveness The comprehensiveness of these components is not as apparent. During the battle, which is really when battalion-level agility is most important, new courses of action are not constantly being sent to the units. A new course of action, called a fragmentary order (FRAGO), is published only when enemy actions warrant a change or modification in the already published operations order. The realization that the enemy actions are not conforming to expected enemy actions is not an easy or automatic task, but its timeliness is critical for success in battle. We should recognize

that a prerequisite of agile actions is quick and accurate military tactical intelligence. The three components of agility are comprehensive even though military intelligence is not included in its definition. A unit will have a high agility conformance rating if it moves quickly, regardless of the wisdom of the moves.

Parsimony The only question regarding parsimony is whether the three components of agility could be as well or better represented with only two categories. For example, physical and non-physical agility would be an alternative set of categories. Combining mental and organizational agility makes the representation simpler and just as comprehensive. However, diagnostically the separate components have more value than a single, confounded component. The responsibility for the actions being measured would not assignable if agility were separated into physical and non-physical components.

Orthogonality Mental, organizational, and physical are components of agility. To attempt to measure agility without first dividing the actions to be measured into separate components would violate the principle of orthogonality. This is the same reasoning as was used in separating victory in battle into offensive and defensive victory. The existence of orthogonality may be clearer with the identification of agents for each component. Specifically, mental agility refers to the commander. Organizational agility is evidenced by the staff that conducts planning and publishes orders. Physical agility is demonstrated by the movement of the unit's assets. Orthogonality has been demonstrated for the proposed components of agility.

Measurability Because there is no readily available metric for mental, organizational, or physical agility, we must develop models that accurately measure these components of Agility. Section 3.5 contains the development of these measures.

3.4.3 Components of Initiative

Initiative is the second tenet of Army Operations. It has intuitive, military, and non-military connotations. Different interpretations can easily lead to subjective differences when measuring or evaluating conformance of battlefield actions to the tenet of initiative. To an officer in the US Army who has learned doctrine from training and evaluation, schools, manuals, and association with other experienced leaders, the meaning of initiative has become, "The behavior of setting or changing the terms of battle." When the enemy is setting the terms of battle, the initiative has been lost. However, lost initiative can be regained. Initiative is not a one-event attribute but a characteristic of a process of planning and acting that forces the enemy to follow your plans.

The glossary of the operations manual [FM 100-5 93], adds that initiative implies an offensive spirit. In the body of the same manual, on page 2-6, a discussion of initiative includes implications shown in Table 3.2.

These ideas yield the following concepts as candidates for representing this particular tenet: Agility, Risk-taking, Decentralization, Surprise, Anticipation, Pressing the Fight, Independence, Freedom of Action, Control of Terms of Battle, Pressure, Offensive Spirit.

Table 3.2: Implications of Initiative from FM 100-5

	Implications of Initiative
1	A constant effort is required to force the enemy to conform to commanders' operational purposes and tempos.
2	Commander retains freedom of action.
3	Commander anticipates events on the battlefield.
4	Commander is willing and able to act independently within the framework of the higher commander's intent.
5	Commander never allows the enemy to recover from the initial shock (during offensive battle).
6	The use of surprise in selection of time, place, and violence of the attack is required.
7	Commander must press the fight.
8	Taking risks is implied.
9	Decentralization of authority is necessary.
10	Initiative requires agility.

Proposed Components

Four components are proposed here that would be most effective in representing and evaluating the level of initiative evident during a battle.

Freedom of Action is freedom from constraints on action due to the enemy, due to the degree of centralization of authority, or due to the commander's own ability or willingness to act independently.

Offensive is the characteristic of being ready to go on the offensive whenever the opportunity arises. Offensive action forces the enemy to react rather than act. It allows the force on the offensive to set the terms of battle [FM 100-5 86].

Risk-taking Involves beginning a task whose rewards or negative consequences is uncertain. Although every decision maker takes a risk in implementing any decision, risk-taking per se occurs when there is an explicit recognition that the rewards and the probability of achieving them outweigh the negative consequences and their associated likelihood of occurrence.

Control the Terms of Battle is to dictate to the enemy when, where, and how the battle will fought. Control is separable into the following subcomponents:

- Control of Tempo
- Control of the location of the battle(s)
- Control of type of battle (i.e., the posture)

Component Selection Criteria

Applicability Freedom of action was chosen as a component because of the importance given it in the main definition from the Operations manual. Freedom of action is the command environment that makes the other areas of initiative possible. The command environment does not refer to the weather or terrain, but to the environment created by the hierarchy of commanders. This component of initiative refers directly to items 2, 4, and 9 in Table 3.2.

Being offensively minded during battle finds its applicability in the 70 year-old principle of war – Offensive. The definition of this principle of war is simply, "Seize, retain, and exploit the initiative." It has been touted by Clausewitz as a key to victory in war [Clausewitz 32], Book 7. Offensive actions are strongly related to items 5 and 7 in Table 3.2 and therefore applicable to the main concept of initiative.

Risk-taking is broad enough to encompass audacity, boldness, and surprise. All involve risk-taking and a major portion of each of these concepts can be parsimoniously represented by this one concept. The applicability of risk-taking to initiative stems from its similarity to items 3, 6, and 8, Table 3.2. Anticipating enemy actions is risky, even with the best intelligence. Surprise involves taking risks. If an action yields benefits without any risks, the action would not be a surprise – it would be expected. Using surprise and boldness to one's advantage involves carefully balancing the risks with the benefits and the likelihood of success. All of these concepts have been tied to both initiative and risk-taking and fit well under the same component.

The applicability of Control of Terms of Battle has been established by definitions, doctrinal manuals, and the experience of many tacticians includ-

ing General N. Schwartzkopf [Schwartzkopf 92], Clausewitz [Clausewitz 32], and General J. Fuller [Fuller 21]. "The behavior of setting or changing the terms of battle" is the operational definition which unquestionably supports applicability. Control of terms of battle is a component containing subcomponents of when, where, and how. Items 1, 5, and 7 from Table 3.2 are related directly to control. Pressing the fight, keeping the enemy off-balance, and forcing them to conform to your operational purposes and tempo all clearly relate to this component of agilty and support their applicability.

Comprehensiveness All of the terms in the doctrinally accepted definitions as well as the intuitive versions of those definitions can be related to one or more of the four components. The long list of descriptors of initiative offered in the beginning of this section are also all contained in one of the four components as discussed in the applicability paragraph, except for one item. The last item in the list is a requirement of agility. To keep the aspects of Army Operations doctrine as orthogonal as possible, the agility concept will not be evaluated within the initiative area.

Parsimony A method for establishing the parsimony of these four components is to model the conformance to initiative with all four and then model the conformance with only three of the components being used. Similar to backward regression, the component that was not needed would be found to be statistically insignificant. Prior to the gathering of data, during this analytical modeling stage, conceptual significance must replace statistical significance. Of the four components, control of terms of battle is the most deeply rooted and necessary measure. Freedom of action has little to do with

movement of assets and selecting courses of action. It is naturally set apart from the other two components and is very applicable, as established earlier. It can not be eliminated or combined. Finally, offensive and risk-taking must be compared. Of the four components, these two are the most similar. Offensive has been shown to be very significant; indeed it is an actual principle of war. Therefore it appears that risk-taking be included under the component of offensive. One might argue that the offensive naturally carries with it a degree of risk. However, so does a defensive battle. Several famous battles, such as the Spartans at Thermopolae, the Texans at the Alamo, and the Iraqis during the Gulf War of 1991 provide prime examples of defensive risk-taking, either of positioning, of timing, or simply of staying to fight. Since risk-taking does not fit exclusively within the offensive component, it appears that parsimony has been satisfied.

Orthogonality Orthogonality between offensive and risk-taking was the reason that parsimony had been achieved. They each had separate and distinct concepts that were not addressed by the other.

The disjointness of control and freedom of action should be clear. Without the ability to control, there is no need for freedom of action. If the friendly forces control the terms of battle for the present, freedom of action is necessary for keeping control. Freedom of action gives the commander the ability to react to enemy actions quickly and to take back the initiative if it was lost. Control of terms of battle keeps and maintains the initiative. Because battle is a contest between opposing forces, and each force wants to control the terms of the battle, there will normally be a flow of control. Both the control and the freedom of action needed to gain or regain control are

important but separate components.

Parsimony A shorter, more concise list of components is not possible. In the process of considering the three previous principles of component selection, a list of ten main concepts has been cut to four components. I have been unable to discover a more parsimonious list that maintains the qualities of this current list – comprehensiveness and orthogonality.

Measurability The measurability of these components is unknown since no direct measures of any of the components have been developed. New measures that transform battlefield data and relate them to a component will have to be designed.

3.4.4 Components of Depth

Depth is described in the Operations manual [FM 100-5 93] as allowing the force to:

- secure advantages in later engagements
- protect the current close fight
- defeat the enemy more rapidly by denying freedom of action and disrupting or destroying the coherence and tempo of its operations.

Proposed Components

Four components of depth are proposed that would most effectively represent the level of depth achieved in a battle.

Planning indicates the detail and the scope of the operational organizational effort. It is meant to be an indicator of the actions of the commander and staff that occur before any execution takes place.

Spatial Depth is the intensity of operations occurring in the rear. in the deep battle, and on the flanks.

Temporal Depth is the degree to which future operations are planned and coordinated, as well as how far in the future enemy and friendly actions are being considered.

Reserves are the amount of support contributed by the reserve force(s). The support can be in the area of security, successful reinforcement of a committed unit, or replacing a committed unit that needs reconstitution.

Component Selection Criteria

Applicability The applicability of these four components is based upon doctrinal discussions pertaining to depth. The Operations manual describes depth as "...the extension of operations in space, time, and resources" [FM 100-5 93]. The spatial and temporal components are clearly supported by this statement. In the Officers' Basic and Advanced courses, a short and effective definition for depth is "plan ahead." These two words imply planning for the future as well as planning for what will happen over the next hill or 40 km away. Either could affect the outcome of the close battle. Good planning is implied in every discussion of depth on the battlefield, and has therefore been selected as a component in representing depth.

The NTC evaluators and trainers check for depth in an operation by monitoring the mission, size, and actions of the reserve force. This is not the only area that monitored but is the one that is reported most frequently. Nearly every operation, offensive or defensive, has a reserve force that will have one of a variety of missions. Reserves can affect the course of the battle because they can quickly add combat power to critical places and at critical times. Reserves also appeal to the intuitive meaning of depth, analogous to depth of a basketball team. If there are many good, talented players who are not in the starting line-up for a team, it is said that the team has good depth. The intuition, combined with the evaluative efforts at the NTC, lend support for the applicability of reserves as a significant component of depth.

Comprehensiveness The results of depth are manifested on the battlefield by momentum in the offense and elasticity in the defense. The characteristics of momentum and elasticity are very similar and therefore combined below:

1. Fix committed enemy forces
2. Sustain operations
3. Provide adequate reconnaissance
4. Interdict uncommitted enemy forces
5. Provide adequate air protection
6. Disrupt enemy command and control
7. Provide adequate reserves and follow-on forces

8. Protect own rear areas

9. Move resources forward (offense only)

10. Project operations into enemy rear areas

11. Prepare supplementary and complementary positions (mainly defense)

Sustaining operations shows proper planning of logistics. Reconnaissance is necessary for good planning in space or time. Interdicting uncommitted forces is spatial depth if accomplished at the right place (unit) or temporal depth if accomplished at the right time, i.e. right *before* an enemy mission is launched. Providing adequate air protection, combined with rear area protection, are part of the planning process. Projection of operations into the enemy rear areas and preparing supplementary and complementary positions are both part of spatial depth. All of the items in the comprehensive list above can be categorized into one of the four components proposed, and thus comprehensiveness has been shown.

Parsimony The definition of parsimony states the smallest possible set of exhaustive components should be selected. Because of the references in the definition of depth to "later engagements," and "disrupt the tempo and coherence," time and space become prospective components. The intuitive meaning of depth led to the inclusion of reserves as a major element. It appears that any comprehensive set of components of depth must contain these three. Parsimony demands that the prospective component of planning be questioned. Planning occurs before and during the battle. Planning must include the mission(s) of the friendly force, the follow-on missions, intelligence

acquired regarding the mission, location, and actions of the enemy, and the resources available. Planning also occurs during the battle as new information becomes available. The behavior during the battle may not demonstrate the amount of planning that has occurred. In other words, the planning part of depth is not always evident by actions on the battlefield but will always be demonstrated by actions during the preparation for battle. Depth is closely related to planning in this sense that it must appear as one of the components. Parsimony is served by keeping planning as a component of depth.

Orthogonality Space and time are certainly distinct and unambiguous concepts that represent different dimensions of the aspect of doctrine. Space refers, in general, to the periphery of the close battle and beyond. Time is a component that only is used to determine when certain actions in the future should occur.

Planning considers both space and time. The part of planning that adds to the analysis of depth is both intellectual and physical but would not be measured during the battle. By virtue of the time it occurs, it is orthogonal to the space and time components of depth.

Finally, reserves are a component completely different from space, time, and planning. Reserves represent a conscious decision on the part of the commander to commit actual combat power specifically designated as reserves. Their size, availability, and eventual commitment are all important to the battle. Many battles have been won or lost due to their appropriate or inappropriate use.

It appears that all four components are orthogonal and qualify for further modeling.

Measurability None of the components is immediately measurable and must therefore be further analyzed. Further modeling of the components of depth is not included in this research but is certainly a critical part of the recommendations for future work (see Section 5.5).

3.4.5 Components for Synchronization

Synchronization was discussed at length in Chapter One where it was introduced and in Chapter Two where its background and roots were explored. As a tenet of Army Operations it represents an aspect of doctrine. Synchronization is defined as focusing resources and activities in time and space to produce maximum relative combat power at the decisive point [FM 100-5 93]. The following items in the definition will be used to develop key concepts for this analysis:

- Focusing in Time and Space
- Resources and Activities
- Maximum Relative Combat Power
- Decisive Point

Proposed Components

The four proposed components related to synchronization are:

Combined Arms Balance is coordinated application of the battlefield operating systems (BOS) during the battle towards a common goal of victory.

Control is the purposeful arrangement of available combat power with respect to both time and space.

Doctrinal Positioning is the appropriate arrangement and placement of friendly combat power with respect to enemy assets and enemy combat power.

Weapons Usage is the actual firing and use of available combat power. The massing of weapons is only effective if, once in place, the weapons are fired.

Component Selection Criteria

Applicability Referring to the doctrinal definition of Synchronization, the focusing of battlefield activities suggests use of the combined arms as well as the combined services. The battlefield operating systems at the disposal of the commander were organized by the Department of the Army as useful for categorizing the many systems that presently operate on the battlefield [FM 25-101 90]. They are:

- Intelligence
- Maneuver
- Fire Support
- Mobility, Countermobility, Survivability
- Air Defense
- Logistics

• Battle Command

An example of combined arms operations when the artillery, the Engineers, and the maneuver units coordinate their actions to maximize the effect of an emplaced minefield by planning both direct-fire and indirect-fire coverage on the minefield while the enemy attempts to breech the it. Use of combined arms during the battle is one concept that is inherent in synchronization.

"Focusing in time and space" indicates control. Level of control is consistently briefed to participants during the NTC After Action Reviews (AARs). Doctrinally and definitionally, control has applicability to synchronization.

Focusing resources and activities at a "decisive point" indicates that there exists a right place. Historically, finding the decisive point has been the most talked about and elusive element of combat decision-making and resulting tactical operations. Applicability is certainly satisfied by this concept of finding the critical point. Because the focus is on matching actual actions with actions prescribed by doctrine, this component will be called doctrinal positioning.

The last critical phrase from the definition of synchronization is "maximum relative combat power." Combat power connotes potential or destructive power, meaning a capability dependent upon attributes such as range, number of weapons, and type of weapons [Dupuy 85] (see OLI in Glossary). Here combat power means something different. Potential does not win battles. Capability does not destroy the enemy or its ability to fight. Only fired weapons accomplish those tasks. Combat power in this case will mean combat power *used* – weapons usage. Killed targets constitute verifiable damage and must be a part of synchronization. Force ratio models assume a cer-

tain rate of fire and probability of hitting and killing the enemy. Lanchester models [Lanchester 14] have an attrition rate based upon the attributes of the weapon systems contained in a unit *and upon an expectation that the weapons are used.*

This measure is necessary in order to provide an indication of how much weapon systems were actually fired. The planning of direct-fire and fire support is important for synchronization, but does not indicate exactly how much actual firing occurred. The number of enemy weapon systems destroyed is an important indicator of battle success, but again does not indicate how many rounds were fired, how many rounds missed, or how many rounds it took to destroy a weapon system. Accuracy is also relevant and is the focus of much individual training. The commander, however, has very little influence upon the accuracy of his soldiers during the battle. Accuracy is related more to performance than doctrinal conformance. Weapons usage should be diagnostically helpful in all of these areas.

Comprehensiveness Using the definition, these four variables are quite comprehensive. They cover the control of the combat power, the positioning of the combat power by doctrinal standards, the use of all of systems available in concert with one another, as well as actually firing the weapons.

Parsimony The four components of synchronization were selected because of their relevance to the definition and use of synchronization. Four main concepts are included in the definition. Deleting one would necessitate combining that idea with one of the others, thus forcing that combined concept to be more complicated, less orthogonal, and more difficult to use diagnostically.

A great deal of parsimony has already been adhered to in keeping the list of components to four. Many concepts are implied by the term synchronization. In conversations with combat officers, ideas such as concentration, focus, timing, coordination, orchestration, sound and detailed planning, full resource use, a massing of assets, economy of force, and planning ahead were offered as key concepts for synchronization. This list of four components is an attempt at being as parsimonious as possible while addressing all of the major concepts involved with synchronization.

Orthogonality The components of synchronization were chosen to satisfy both the definitional requirements and orthogonality. Weapons usage does not depend upon the location of the enemy forces or the location of the weapons fired. Care must be taken that a measure of combined arms does not require dependence upon other components such as weapons usage. The control variable could easily involve some dependence upon doctrinal positioning and possibly even combined arms. It is clear that the orthogonality question will not be settled until the measures used to indicate the levels of these four variables are defined and compared for separateness and mutual exclusivity.

Measurability None of the components of sychronization are directly measurable or even observable. Each component has at least two subcomponents which will also need measurement before measuring the component. The subcomponents will be identified in Section 3.6 as well as models for measuring them.

3.4.6 Normalization

As the analysis proceeds into developing measures of components and subcomponents of the tenets, each measure will need to be normalized. There are two goals of the normalization process.

First, the users of the measures of conformance to doctrine must be given something more than numerical results. They must be given a benchmark or a scale against which they may judge the results and make qualitative evaluations. A normalized value will provide two benchmarks – a theoretical or doctrinal low value and a maximum feasible high value. The normalized values developed here will also carry with them a constant scale – from 0 to 1.

Second, to be generalizable, a meaningful value should be comparable to a value of the same measure from some other battle. The other battle may be between different units, using a different mix of weapon systems, and possibly with different missions. To allow such comparisons, the normalization process should produce a value which indicates conformance to doctrine, based upon the assets, resources, and mission for that battle. A light Infantry unit armed mainly with light weapons and moving on foot, should be able to conform to the doctrinal component of Physical Agility as well as the fast, powerful, and heavily-armed Armor unit.

For each measure developed, the normalization procedure will be discussed. The effect of the assets and resources available will be negated and lowest and highest possible values will be identified. The position of the actual value between the lowest and highest possible will yield the measure's value. For the remainder of this paper, this value will be called the measure's

normalized value.

In Section 3.4 we have developed several subcomponents of each of the four components of action. Figures 3.6 and Figure 3.7 show how these subcomponents expand the components of Agility, Initiative, Depth, and Synchronization. Now, in Section 3.5 we will develop normalized quantitative measures for each of the subcomponents. At the level of quantitative measures for subcomponents, we will interpret the measurability criterion as requiring that the measures can be computed objectively from data already available for NTC exercises or already maintained in simulation databases for simulation exercises, with a possibility for exceptions where current exercises or databases can be argued to be inadequate.

3.5 Measures for Components of Agility

3.5.1 Measures for Organizational Agility

Proposed Measures

Acting and reacting can be interpreted to mean producing deliverables. A battalion staff produces two main deliverables:

1. Published Operations Orders

2. Published Fragmentary Orders

Deliverables one and two go to the subordinate units. Both deliverables are dependent upon the commander for decision-making. Timing is usually critical and the less time expended on either deliverable, the more effective the action or reaction is considered to be. Both the quality and the timeliness of the deliverables are affected by several factors including:

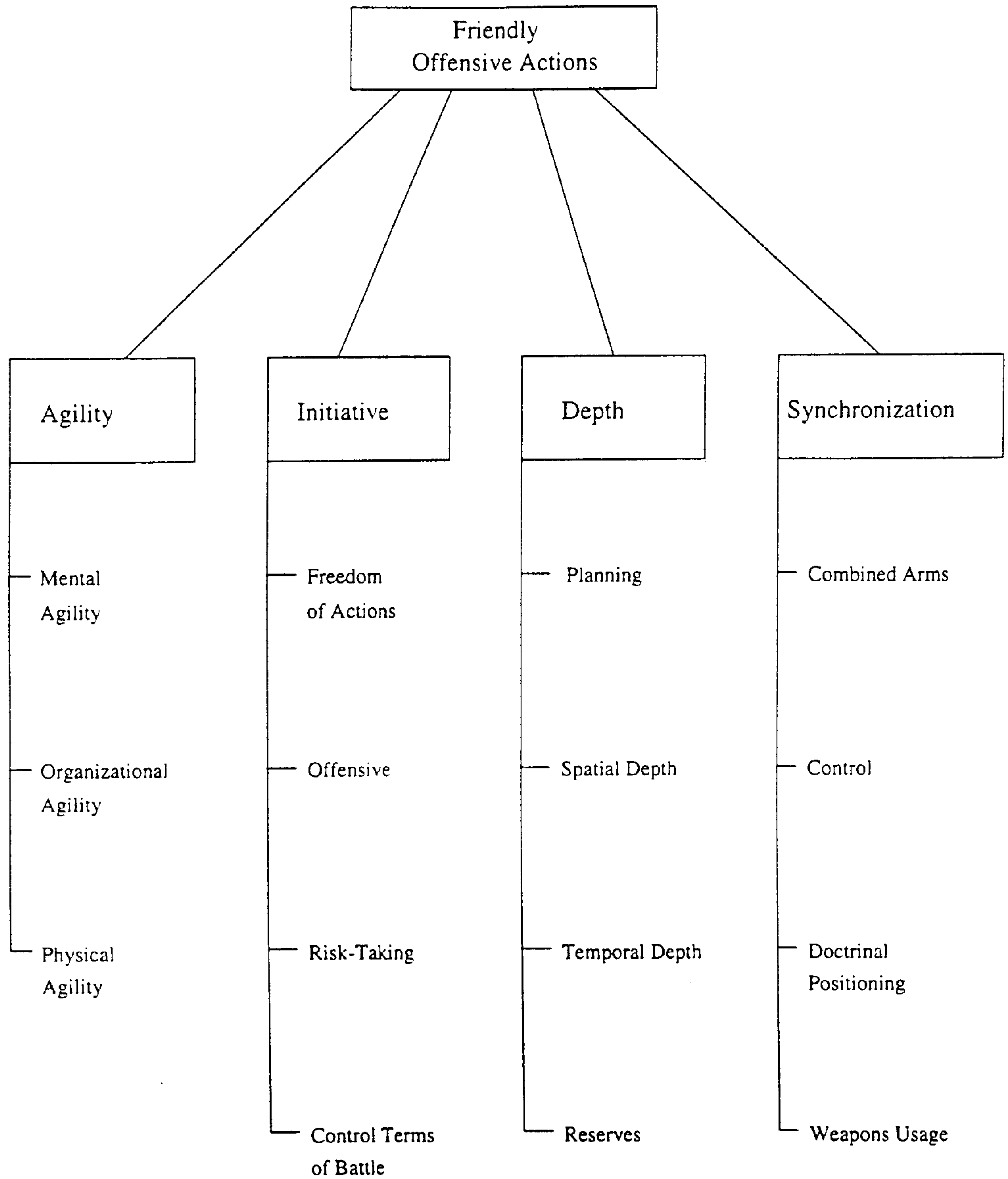


Figure 3.6: The Hierarchy of Diagnostic Components of Friendly Offensive Actions

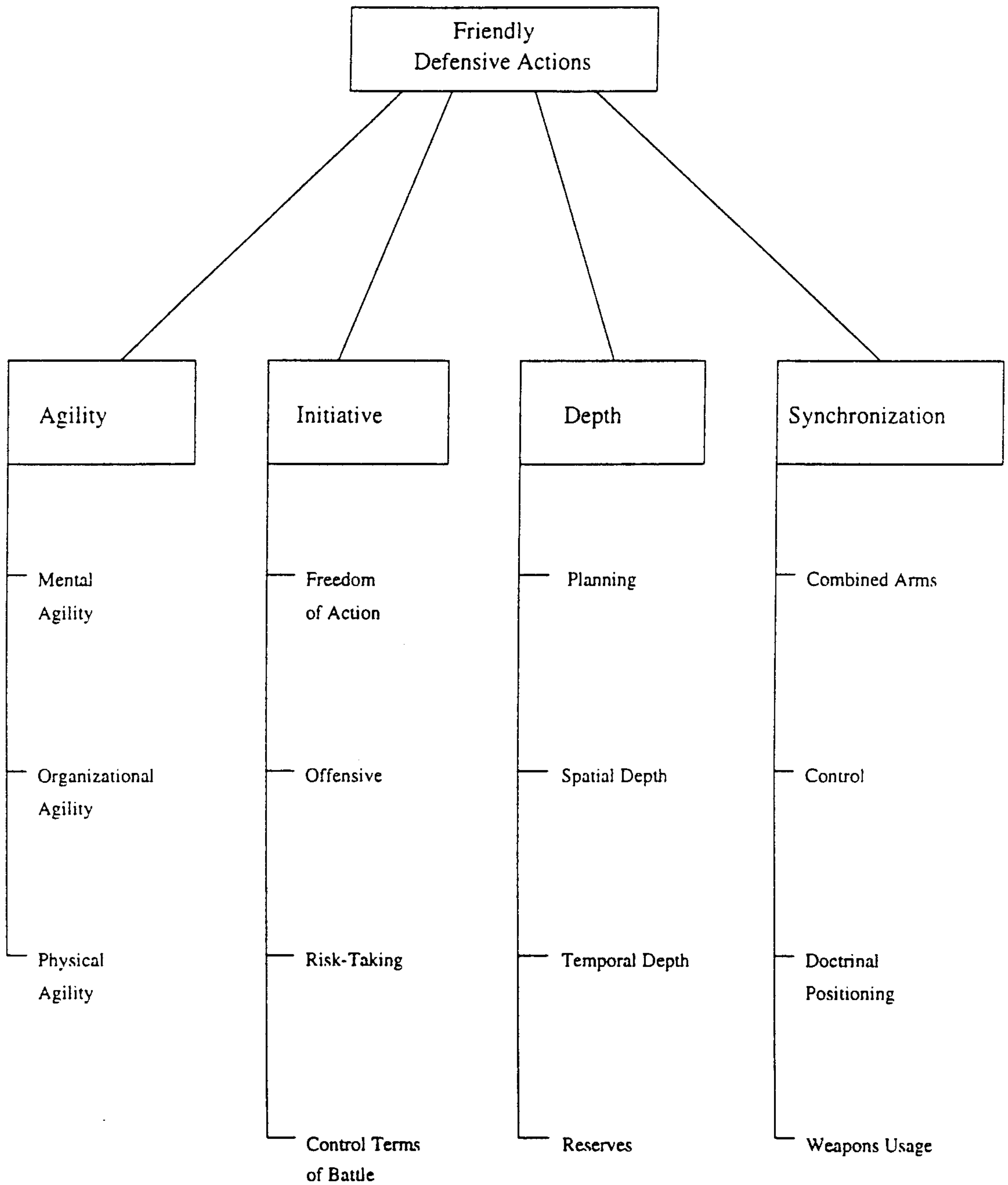


Figure 3.7: The Hierarchy of Diagnostic Components of Friendly Defensive Actions

- Quality of the Staff
- Quantity of the Staff
- Quality and comprehensiveness of the standard operating procedures (SOPs)
- Number and quality of prepared courses of action

Applicability Since the goal of this component is to evaluate the manifestation of agility and not the resource intensive capability to be agile, the quality and quantity of the staff and the quality of the SOP will be considered resources and therefore not applicable.

The applicable measure for organizational agility is speed. Speed refers to how fast a course of action can be designed, wargamed, offered, and finally published as an order. The preparation that goes into such actions is undeniably important but difficult to quantify and not evidenced as a battlefield action. Speed, as the one organizational activity that can be both observed and measured, will be modeled. Published orders can be divided into publishing operations orders (OPORDs) and publishing fragmentary orders (FRAGOs). We will develop a model which takes the speed of publishing both OPORDs and FRAGOs.

Comprehensiveness The speed of publishing an order is the result of all efforts that combined to produce the order. It is a measure of the successful combination of preparation, teamwork, problem-solving, and wargaming.

Parsimony The orthogonality of the speed of publishing operations orders and the speed of publishing fragmentary orders is through use of resources at different times in the battle. The effects of these two measures are also quite separate. The operations order affects the timing of all of the preparations of the subordinate units prior to the battle. The detailed and comprehensive orders lay the foundation for the entire conduct of battle. The FRAGOs are reactive in nature and affect the initiative of the subordinate commanders and the mobility of the unit's operations.

Measurability Speed can easily be measured if the times for staff actions are recorded. The publishing time is a key indicator of the speed of the staff actions. We will consider the publishing time to be the time it takes to publish an order from the receipt of a course of action decision by the commander to the time the order is given to the subordinate units.

Modeling

The proposed model for organizational agility is:

$$OA_{speed} = .5 * \sum_{m=1}^{M} \frac{MIN[1, \frac{3}{2} * (1 - T_{F_m})]}{M} + .5 * MIN[1, \frac{3}{2} * (1 - T_O)]$$

and

$$T_O = \frac{t_O}{T_{AO}}$$

$$T_{F_m} = \frac{t_{F_m}}{T_{Am}}$$

where:

T_O is the proportion of time it takes to publish the Operations Order.

t_O is the time it takes to publish an order from the receipt of a course of action decision by the commander to the time the order is given to the subordinate units.

T_AO is the total time available to the staff for publishing the OPORD.

T_{F_m} is the proportion of time it takes to write and publish FRAGO m.

t_{F_m} is the time it takes to publish a FRAGO from the receipt of a change in plans from the commander to the time the order is given to the subordinate units.

T_AO is the total time available to the staff for publishing FRAGO m.

M is the number of fragmentary orders published and given to the subordinate units.

Parsimony The simplest, most parsimonious model that retains the greatest degree of fidelity is the average speed of development of a course of action. The calculation requires only the number and times needed to develop the orders.

Generalizability This model is generalizable in that it is independent of the type of unit and the type of battle being fought. It is restricted, however, to use in comparing or battalion-level units since orders and courses of action take longer in the higher level units and shorter in the lower level units. It would be more generalizable if it could be normalized by the type of action. either COA or FRAGO.

Fidelity The operations order and the fragmentary orders are given the same weight. Of course, if there are no fragmentary orders throughout the battle, then the entire measure would depend upon the speed of publishing the operations order.

Normalization Normalizing occurs by using the $\frac{1}{3}$ - $\frac{2}{3}$ rule-of-thumb as the maximum or most desirable value. If publishing takes longer than 1/3 of the available time, the value $\frac{3}{2} * 1 - T_O$ will be less than 1.0 and so will the measure's value. As T_O approaches 1 (i.e., the staff uses all of the time to publish the order), the value of the measure approaches 0.0.

3.5.2 Measures for Mental Agility

Proposed Measures

Unlike organizational and physical agility, mental agility involves only one entity, the commander, doing a task that is nearly impossible to observe. His mental agility is his ability to make quick decisions about the course of action that the unit takes. Although a commander is constantly wargaming different courses of action or different branches of a course of action, the only evidence of his thought occurs when additional information is offered and he decides on a course of action. The speed of his decision-making is an indicator of his mental agility. The number of changes the commander is willing to make in his plan is also a sign of agility. The two measures that are selected as indicators of the manifestation of mental agility are:

- Speed of decision making
- The number of changes to the plan that are ordered

Measure Selection Criteria

Applicability The applicability of speed of decision making to the manifestation of mental agility is high because it represents a measure of the quickness – a word taken from the definition of mental agility.

In the martial arts and personal combat, an agile person not only has to act quickly but act and react in different directions, perhaps changing plans of action several times. The more changes take place, the more evidence there is of agility. This does not infer that more changes are always effective. There is also no inference that the changes were appropriate. It *does* infer that a high number of changes indicates a willingness and capability of the commander to decide to change his plan. This is a manifestation of a commander's mental agility.

Comprehensiveness The two measures of speed and the quantity are not comprehensive in that neither the quality nor the importance of the decisions are taken into account. Trying to evaluate the importance of any decision in battle is a very subjective matter and one that would be difficult to standardize. The quality of a decision is an even more difficult measure to standardize. Without a simulation of the battle in which a different decision is made and the results recorded and compared, such an evaluation would be merely hypothetical. The two measures do represent a comprehensive list of the *observable* elements of the manifestation of mental agility.

Parsimony To be any more parsimonious, the representation of mental agility would have to leave out either speed or number of changes. Both of these are critical to the meaning of mental agility, as discussed in the

applicability paragraph above and would seriously affect the fidelity of the model if omitted.

Orthogonality The speed and the number of decisions to change the already issued orders are two very distinct and unambiguous measures. They represent different dimensions of an indicator of mental agility.

Measurability The measurability of the mental agility measures is theoretically very possible. It should not be difficult to time the decision-making process of the commander as well as count the number of changes. Counting the number of changes is actually possible to accomplish post hoc. The timing, however, is not currently measured and would require approval by the trainers at NTC. Perhaps, as commanders utilize computers more before and during the battle, automatic timing of decisions will be possible. Possibly an electronic log that records all decisions and the receipt of decision critical information will be available.

Modeling

The Model The manifestation of mental agility will be modeled using speed and number of changes to the operations order. This model will be similar to the model of organizational agility except that it will also account for the number of decisions.

$$MA_s = \frac{N}{\sum_{n=1}^{N} T_n}$$

$$MA_n = N$$

where:

MA_s is the speed portion of Mental Agility.

MA_n is the number of changes portion of Mental Agility.

N is the number of changes to the Operations Order made by the commander.

T_n is the time it takes to make a decision on change number n.

Parsimony Because both the number and speed (number of decisions per hour) are important, they will both be tracked and allowed to influence the overall indicators of agility. Keeping these separate is relatively simple and has more diagnostic value than some arbitrary combination of the two measures.

Generalizability This is an extremely generalizable model that should be valid for all types of units in nearly all combat situations. The data gathered will indicate if higher level commanders take longer to make decisions or if they make fewer decisions. Until that data is available, it will be assumed that these most parsimonious models are generalizable to commanders at all battalion-level units.

Fidelity Good data and reliable evaluations will be the key to the fidelity of the model. If the measurements are accurate, there is no question of fidelity. However, the combination of the two models, MA_s and MA_n will affect the fidelity of Mental Agility.

Normalization No normalization has been attempted for this measure. Empirical normalization, e.g., using percentiles, may be the only useful method of normalization and this can only occur after a relatively large number of battles have been measured.

3.5.3 Measures for Physical Agility

Physical agility refers directly to quick action with as much force as possible. Measures of speed and force are implied. Traditionally, an ability to move force quickly has been called mobility. Since this is also a capability and not a behavior, let *maneuver* represent the manifestation of mobility, or the act of moving combat power quickly. Maneuver is an applicable measure representing the manifestation of physical agility. This one measure is both applicable and comprehensive.

Proposed Measures for Maneuver

Maneuver is a component of behavior that reflects how quickly combat power is actually moved about on the battlefield. From this definition, the first attempt at measure selection should be combat power and speed. Speed has subcomponents of time and distance. The three components of maneuver are:

- Combat Power
- Time
- Distance

Measure Selection Criteria

Applicability Applicability is determined directly from the definition of maneuver which is the movement of combat assets on the battlefield. To measure movement in a diagnostic sense, one must know the speed. If all of the assets are not of equal value, one must also measure and account for the value of individual assets. In this case, the modified Operational Lethality Index (OLI)[Dupuy 85] of each asset is its relative value. We have intuitively referred to this value as its combat power. To measure maneuver diagnostically, time, distance, and combat power are the important, applicable measures to consider.

Comprehensiveness The only other dimension of movement that traditionally has had meaning with respect to physical agility is direction. Direction has been left out of this representation because measuring direction would require comparing it against a proper direction. Measuring proper direction involves knowing the correct direction. The correct direction is not addressed doctrinally nor is this information normally available on the battlefield. The measure for physical agility will not include direction. Because the other dimensions of movement, time and distance, are being measured as well as the measure of combat power, OLI, comprehensiveness will be satisfied except for direction.

Parsimony With respect to the number of measures, parsimony has been met. If position (x,y) had been used instead of distance, no more information would have been gained since direction is not modeled. Only the information needed for adequate comprehensiveness are used for this representation.

Orthogonality Time and space are classic orthogonal concepts and continue to be orthogonal in this situation. Neither an increase or decrease in time necessarily increases or decreases the distance involved. They are distinct concepts. Combat power, considering the method in which it is calculated, is unrelated to either time or space (distance) and is intuitively a distinct concept.

Measurability OLI allows us to measure the combat power of any weapon system. Once distinct movements are identified during the battle, both the time and distance of movements of each weapon system can be calculated by simple manipulation of the data which is in the form of the time and location of each firing unit during each time period.

The Model

In modeling the measure of maneuver, the criteria of parsimony, generalizability, and fidelity will be used to guide the process. A mathematical function is needed that will relate these concepts appropriately. Since the desire is to describe the manifested ability to move combat power over a distance in a short amount of time, the dependent measure – *maneuver* – should vary directly with the distance moved and the amount of combat power involved in the move. For a specified time, the greater the combat power that is moved, and the greater the distance it is moved, the greater the measure of maneuver. The distance component should vary inversely with time because it is the concept of speed that is important. This preliminary analysis leads one to the following general form:

$$Maneuver_i = C * \frac{CombatPower_i * Distance_i}{Time_i}$$

where i is the index that represents a combination of weapon systems and their specific movements during the battle.

The maneuver value for one move can be normalized by dividing by the maximum speed attainable by each weapon system. Since no one move can be expected to be an accurate measure of the maneuver of a unit, a method must be found to estimate the actual *Maneuver*. An average speed for each weapon system is calculated and divided by the maximum attainable speed. The resulting measure is:

$$Maneuver = \frac{\sum_{j=1}^{J} \frac{P_j}{S_j} \frac{\sum_{k=1}^{K} D_{jk}}{\sum_{k=1}^{K} T_{jk}}}{\sum_{j=1}^{J} P_j}$$

where:

P_j is the combat power (OLI) of weapon system j.

J is the number of weapon systems in the unit.

K is the number of moves made by the unit. Each move may not involve every weapon system.

T_{jk} is the time it takes to travel the kth move with the jth weapon system.

D_{jk} is the distance weapon system j moves during move k.

This formula represents weighting individual speed scores by the amount of combat power that traveled at that speed. The scores are then summed and divided by the sum of combat power figures for every weapon system being tracked. The score will necessarily be between 0 and 1 with 1 representing every weapon system maintaining maximum speed for every move. Moves are defined as changes in position greater than 10 meters.

Modeling Criteria

Parsimony The model is parsimonious because it simply sums normalized weighted scores using the three necessary variables identified above. The only way to be more parsimonious would be to leave out the normalization or the weighting.

Generalizability The normalization gives the model its generalizability to any weapon system that has an OLI factor. The weighting of the speed values is necessary for fidelity. Without it, every weapon system's speed would be equally weighted and it would seem not to matter which weapon system makes the movement the quickest. In reality, the commander wants the most amount of combat power to reach the destination as quickly as possible. The system with the most amount of combat power will be of more value to the commander than a weapon system with very little combat power. This model should be valid for any level unit that moves its assets around the battlefield. However, the commander of an artillery unit that is supporting a defensive operation and has little or no movement during the battle (a tactic which is not usually recommended due to accurate

counterbattery fire) may not receive much diagnostic use from this model of maneuver. While maneuver is always important, maneuver in the offense would probably show more correlation with victory than maneuver in the defense.

Fidelity The analytical fidelity of this model stems from the basic relationships between maneuver and time, distance, and combat power. If the maneuver score increases directly with the average speed of a certain weapon system, the score has meaning. Also consistent with that meaning is the relative importance of each of the weapon systems based upon its own OLI or combat power. This model does not measure the change in combat power potential on the battlefield due to realignment of the weapon systems rather than physical movement.

3.5.4 The Structure of Agility

The components – Mental, Organizational, and Physical Agility – have been proposed and supported. Measures have been developed that give applied meaning to the components. Not all measures are currently calculatable based upon the data available. However, the measures that can be calculated will be demonstrated in the example at the end of this chapter and tested in Chapter 4. Figure 3.8 represents the final diagnostic structure developed for Agility.

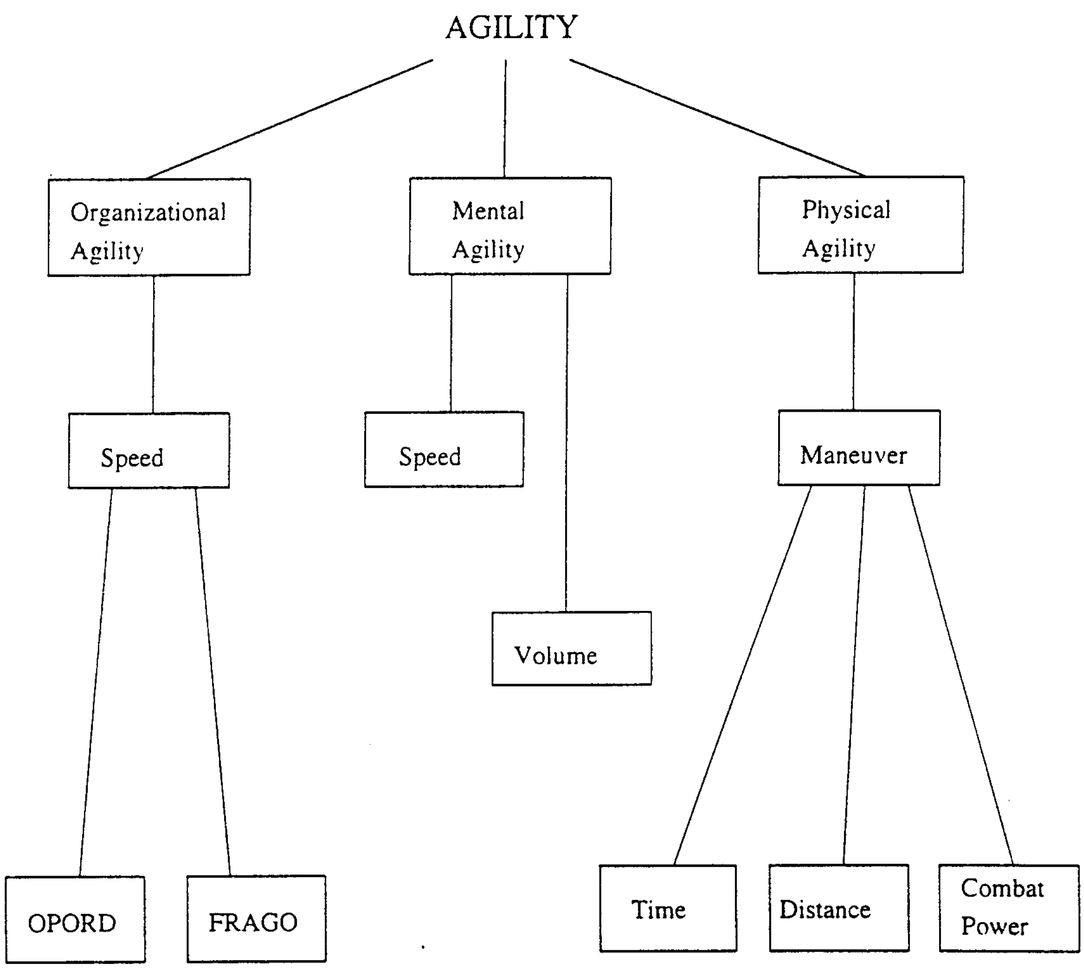


Figure 3.8: Structure of the Components and Measures of Agility

3.6 Measures for Synchronization

In this section new measures from observable, obtainable battlefield data will be developed for each of the components of synchronization developed in Section 3.4.

3.6.1 Measures for Combined Arms

To use only the Armor or Infantry when other combat assets are available is to seriously violate the tenet of Synchronization. Both the documents associated with tactical doctrine [FM 100-5 93] [FM 25-101 90] and the evaluations at the NTC (see Appendix A) stress the use of all of the assets available to the commander as a critical part of synchronization.

Proposed Measures

The Operations manual [FM 100-5 93] cites the Battlefield Operating Systems (BOS) as the prescribed way to solve the synchronization problem. Although not stated explicitly, this organization of battlefield assets was designed for analysis and diagnostics. The Battlefield Operating Systems are:

- Maneuver
- Fire Support
  - Field Artillery
  - Mortars
  - Naval Gun Fire
  - Air Force

- Air Defense
- Mobility, Countermobility and Survivability
- Intelligence
- Battle Command
- Logistics

The BOSs that are applicable to synchronization are those that are briefed during discussions concerning synchronization by the Training and Doctrine Command (TRADOC) and the staff at the NTC. They are the BOSs that actually destroy enemy assets.

- Maneuver
- Fire Support
- Air Defense
- Mobility, Countermobility, and Survivability

Selection Criteria

Applicability TRADOC states that these BOSs are the best diagnostic categories available. Doctrinally, they separate the different types of weapon systems. The applicability of the combat engineer battlefield operating system of mobility, countermobility, and survivability has sometimes been questioned [FM 100-5 86]. However, the systems such as minefield laying, minefield breaching, rivercrossing, roadbuilding and destruction, and a multitude of other similar systems have a definite capability to multiply combat power

and will be included as a BOS throughout this paper. The categories named are applicable because many of the major functions, units, and systems operate entirely inside of a BOS. This particular organization of combat functions and activities has become accepted throughout the military.

Comprehensiveness The list of four categories is not comprehensive with respect to combat activities but it is comprehensive with respect to control of combat power. Not included in the measure are such categories as battle command, logistics, and intelligence. Neither the positions of these systems nor the purpose of any movement nor a list of each vehicle's cargo are currently tracked. More detailed data will be needed to include the other categories of systems in the measure. Presently, the four groups mentioned contain all of the systems that are designed to destroy the enemy.

Parsimony Parsimony with respect to the number of subcomponents involved could only be improved by combining one or more of the four BOSs. Due to orthogonality requirements, as well as the need for usable, diagnostic figures, the number must remain at four. The systems are grouped by type of delivery and by unit commander. This appears to be the most functionally parsimonious method.

Orthogonality As stated in the previous paragraph, the BOSs were designed not only to be comprehensive, but to be orthogonal. TRADOC's organization of the battlefield placed every system into only one category, and distinguished between categories by:

1. The purpose of the system

2. The type of delivery

3. A common commander or staff officer who is responsible for that system's performance

Such a separation causes the diagnostics to be straightforward, meaningful and guarantees orthogonality at an operational level. As an example, the BOS methodology groups naval gunfire, mortars, and field artillery into a BOS called Fire Support. The purpose of all systems is to use indirect-fire to destroy the enemy. All three systems are controlled on the battlefield by the Fire Support Officer (FSO) who plans their use and takes responsibility for their actions.

Modeling

The most desirable quality of the combined arms balance measure is that all of the arms be used in balance. Since no one algorithm can state what the correct balance is for any given battle, and that is certainly not the aim of this work, an algorithm which calculates the objective balance will be developed. The numerical value of this measure will increase as the statistical balance between the arms increases. A statistical method of measuring the balance of several scores or numbers is to calculate the variance of the numbers. Because deterministic values rather than probabilistic values are being considered, the term variation will be used instead of the term variance. If the values for the BOSs are normalized values of the level of usage of each of the applicable BOSs, then the variation calculation will be representative of how the numbers vary compared to the mean established by all of the values of each BOS. The combined arms measure of synchronization will

be calculated by first obtaining normalized values representing the level of use of each of the combined arms. The variation of these values, calculated exactly like the familiar population variance, indicates the lack of balance. A high variation indicates a lack of balance among the different combined arms, whereas a low variation indicates a very balanced effort. The following model shows how to calculate the combined arms variation value:

$$Var = \frac{\sum_i (BOS_i - BOS_{mean})^2}{I}$$

$$and$$

$$0 \leq BOS_i \leq 1$$

The normalization of each BOS value should be based upon the amount of weapons usage that is possible. Each normalized value will be the ratio of the combat power used over the total amount of combat power available, usually due to the basic load. Below are the descriptions of the normalized values for each of the BOSs.

Parsimony The model stated above must analyzed both for its parsimony as a computational model and for the parsimony of each of its weapons usage scores. The variation computation, taken directly from the well-known variance computation from probability and statistics, is a simple yet mathematically sound method for representing the spread of a group of numbers. The square term is used to avoid the problem of scores being on either side of the mean. Another candidate for this computation was the average absolute value of the difference between the mean and the individual scores. This would yield a value just as valuable and just as robust. However, recogniz-

ability and acceptability by analysts as well as nontechnical users favored the variance computation technique.

Generalizability This model should be generalizable across all levels of combat since the scores are the result of normalization. There is no claim implied that each score should be 1.0. The only measure is how close the BOS values are to each other - representing balance. Such a value should be valuable to divisions as well as battalions. It should carry meaning for Armored, Mechanized, and Light Infantry units.

Fidelity The variation calculation's robustness is well-known. Mathematically, if one agrees that high variation implies a lack of balance, the model has a high degree of fidelity. There cannot be a serious imbalance without the variation score shown here reflecting it. The variation values are not meant to have any absolute value. They should give a commander an idea of how balanced the attack or defense was based upon actual weapons usage. The plans for usage, in this calculation, are not important, as they are not important to the results of the battle - just the actual weapons usage. Since the BOS values are normalized, a more detailed question of fidelity falls mainly on the fidelity of the BOS scores and the normalization methods. These are discussed in the following four sections. Diagnostically, if the variation value has been noticed as being too high, each of the normalized BOS values can be analyzed to see which of the combined arms was a main contributor to the high variation.

Normalization Normalization here is accomplished first by only measuring the variation between already normalized BOS values. Second, the normalized value is forced to be between 0 and 1 by identifying the minimum and maximum possible values of the variation. This is possible because the model works only with normalized values which are themselves between 0 and 1. With four values, the minimum possible variation, thus the highest balance of combined arms, is 0.0, indicating the BOS values are identical. The highest variation is 0.25. This occurs only if two of the BOS values are each 1.0 and the other two are each 0.0. This is the most imbalanced the combined arms use can be and should receive a value of 0.0.

Maneuver BOS The maneuver portion of combined arms includes the direct fire weapons systems found mainly in the Armored and Mechanized Infantry Platoons. Included is the support from air assault units. Each of the weapon system types are evaluated as to the total number of rounds fired during the battle.

$$Maneuver = \frac{1}{CbtPwr_{Maneuver}} * \sum_{i=1}^{I} V_i * CbtPwr_{rd_i}$$

where:

I is the number of distinct weapon systems in this BOS

$CbtPwr_{Maneuver}$ is the total amount of combat power available from all of the rounds in the basic load from every weapon being considered as a maneuver asset.

V_i is the volume of rounds fired from the ith weapon system.

$CbtPwr_{rd_i}$ is the amount of combat power in 1 round from weapon system i.

Fire Support BOS The Fire Support value will be calculated similarly to the maneuver value. Included in fire support are all mortars, howitzers and cannons, the Multiple Launched Rocket System, naval gunfire, and Close Air Support. The calculation is:

$$FS = \frac{1}{CbtPwr_{FS}} * \sum_{i=1}^{I} V_i * CbtPwr_{rd_i}$$

where:

I is the number of distinct weapon systems in this BOS

$CbtPwr_{FS}$ is the total amount of combat power available from all of the rounds in the basic load from every weapon being considered as a fire support asset.

V_i is the volume of rounds fired from the ith weapon system.

$CbtPwr_{rd_i}$ is the amount of combat power in 1 round from weapon system i.

Air Defense BOS Air Defense plays a key role in any battle in which the enemy has air capability. The Air Defense BOS is often referred to as Air Defense Artillery (ADA). Since the friendly commander has no control over the use of enemy aircraft and will not fire ADA assets unless needed, the positioning and availability of ADA assets rather than the actual firing

of them will be used to generate the Air Defense value. If critical events occur during the course of the battle and the friendly forces are covered by ADA assets (i.e., within ADA assets' range) then the intent of the combined arms doctrine has been met. The value will represent the average percent of friendly forces, including combat, combat support, and combat service support units, that were adequately covered by ADA assets.

$$AD = \frac{1}{T} * \sum_{t=1}^{T} P_t$$

$$and$$

$$P_t = \frac{CbtPwr_{P_t}}{CbtPwr_{tot_t}}$$

where:

T is the number of time periods in the battle.

P_t is the percent of friendly forces within effective ADA defensive coverage.

$CbtPwr_{P_t}$ is the amount of friendly combat power that is adequately protected in time period t.

$CbtPwr_{tot_t}$ is the total amount of friendly combat power on the battlefield at time t.

Mobility, Countermobility, and Survivability (MCMS) The combat engineers have different responsibilities in the offense compared to the defense. In a deliberate defense, the engineers are responsible for digging/constructing fighting positions for the mechanized and armored companies/teams. If possible, each armored vehicle (M1A1/2) should have one main position, one

alternate position, and a supplemental position. The mechanized fighting vehicles (M2A1/M113A2) should also have main, alternate, and supplemental positions. There are other responsibilities such as laying minefields at planned locations for purposes of denial or canalizing the enemy into a kill zone. The engineers are also the experts in both bridge construction and demolition. The scoring or measuring of these tasks are accomplished by analyzing the percent of required positions dug, the percent of available mines laid, and the degree to which they were used to create other obstacles that might slow, stop, or change the enemy's course. In general, the engineers' mission in the *defense* is countermobility and survivability.

$$MCMS_{Def} = K1 * A + K2 * B + K3 * C + K4 * D$$

$$K1 + K2 + K3 + K4 = 1$$

where:

MCS_{Def} is the BOS value for mobility, countermobility, and survivability element of the defensive effort.

A is the percent of available mines that were laid.

B is the percent of primary positions dug to standard.

C is the percent of supplementary positions dug to standard.

D is the percent completion of obstacles, other than mines, that were planned for the battle.

K1-K4 are constants that indicate the relative importance of the categories of MCMS, initially equal to .25.

On offense, the engineers' main task before the battle consists of assisting rear echelon units prepare a defense before the friendly attack begins. During the battle, they are required to clear any obstacles found that cannot be bypassed, appropriately mark the known obstacles if necessary, and construct bridges over obstacles if appropriate. Measurement can occur by indicators of use of the engineers where appropriate. In other words, in each instant of need of engineer support, were the soldiers and equipment available, were they used effectively? In general, in the offense, combat engineers concern themselves with mobility. The intent of this BOS measure is not to indicate how well the engineers perform, but to measure how much the engineers were used. This is a subjective value that should range from 0 to 1 for each instance which called for assistance with mobility. It is the average ratio of mobility and countermobility efforts at identified sites over the total amount of possible effort as measured by the engineering hours and equipment available.

$$MCS_{Off} = \frac{\sum_{i=1}^{N} \frac{EVAL_i}{Max_i}}{N}$$

where:

MCS_{Off} is the value for mobility/countermobility in the offense.

N is the No. of mobility problems encountered.

$EVAL_i$ is an evaluation of the equipment hours used at each site of a mobility task.

Max_i is the estimated maximum number of equipment hours available at each site.

Summary for Combined Arms

The final calculation for the combined arms measure is to compute the balance of the combined arms effort by calculating the variation of the five normalized scores.

$$CA_{var} = \frac{\sum_{i=1}^{4} [BOS_i - BOS_{mean}]^2}{4}$$

where:

CA_{var} is the combined arms measure.

BOS_i is the normalized value for the *ith* BOS.

BOS_{mean} is the mean of the four normalized BOS values.

The above model is quite parsimonious in that it does not attempt unnecessary or extremely complicated calculations. The concept is an intuitive one that yields a single useful value. The normalization process helps make the model more generalizable. The model can also be broken down into individual normalized values for diagnostic purposes. Knowing that a commander has a high variation, and thus a low value for combined arms balance measure, is an indicator of how the commander conformed to combined arms doctrine; but it is of limited use. Knowing which of the combined arms was overemphasized and which was underutilized increases the usefulness of the information. It can be easily portrayed by either graphical or numerical comparisons of the BOS values.

Orthogonality of Combined Arms vs. Weapons Usage The variation used in the combined arms measure is largely independent of the Weapons

Usage score which represents the weighted mean of the BOS values. Whether the weighted mean is high or low does not significantly affect the variation of the BOS values. However, as the weighted mean approaches its upper limit of 1, the variation approaches zero, i.e., all of the individual values are 1 thus the variation is zero.

$$WeightedMean = 1 ==> BOS_i = 1$$

For all i. If

$$Var = \frac{\sum_i (BOS_i - BOS_{mean})^2}{I}$$

and $BOS_{mean} = 1$ since for all i $BOS_i = 1$, then

$$Var = \frac{\sum_i (1-1)^2}{I} = 0$$

Similarly, as the weighted mean approaches its lower limit of 0, the variation is forced to 0 since all of the individual values approach zero.

$$Var = \frac{\sum_i (0-0)^2}{I} = 0$$

Therefore the variation of the BOS values and the weighted mean of those values are not independent over the range of Combined Arms values. However, complete mathematical independence is not necessary to establish conceptual orthogonality. When the weighted mean value for Weapons Usage is not near the limits, the range of possible variation values for combined arms balance increases dramatically. Conceptually, the ideas of balanced use and total, weighted use are different and unambiguous. Adequate orthogonality, if not independence, is claimed for these two measures.

3.6.2 Measures for Control

Subcomponent Selection

Control is exercised by a commander and his staff through many media including published orders, Standard Operating Procedures (SOPs), which are established prior to the battle, and control measures that take place during the battle to coordinate and synchronize assets to react to unforeseen or unplanned-for events. Ability to communicate, both in terms of electronic communication and conceptual communication, is essential for control. Another factor for good control is the relationship between the commander, his staff, and the subordinate units. SOPs and rigorous training also enhance the ability to control battlefield actions. While these factors and others reflect the potential or ability to control, only the actions implemented during combat demonstrate the actual control that is acquired. The real-time control actions that occur during battle are electronic, written, visual, or verbal. It would be very difficult to attempt to measure how much control takes place on the battlefield by measuring how much communication takes place or by measuring the quality of the SOPs or published orders. These are all very subjective factors, very difficult to quantify, and harder to standardize. The actions on the battlefield represent the direct result of all of the efforts to control. To use an analogy, consider a dog show. The judges do not consider how much talking, cajoling, or whistling the dog owner does. What counts are the actions of the dog – the results of the control efforts. Similarly, it should be simpler, more direct, and more reliable to measure the actions of the players on the battlefield than to try to measure and evaluate the actions of control.

Proposed Measures

On the battlefield, the only things the commander can control are:

- Where assets are placed
- When assets either fire or are in place

Assets refer to combat power. Using this restriction of what can be measured as results of control and the definition of synchronization which includes the phrase, "...focusing resources and activities in time and space..." two types of control are suggested – spatial and temporal.

Applicability The applicability of spatial and temporal control was established in the above discussion when the scope of control was defined.

Comprehensiveness The two measures represent a set that is comprehensive, again determined by the two areas of control indicated by the definitions of control and of synchronization. Other dimensions that might be included in control would be direction, purpose, or weapon type. Direction is important only in how it affects the results – where and when are the assets positioned. Purpose addresses why the assets are positioned as they are. A commander's intent is stated in the operations order. However, judging the positioning of an asset based upon the commander's intent would be nearly impossible. Another, more objective measure of positioning that compares positioning to basic tactical doctrine will be introduced in the following sections. Measuring weapon type would consist of comparing the enemy weapons mounted against the friendly force, the terrain, the weather, the mission, the availability of other weapons, and the capability

of the weapon itself. Instead of involving so many different systems in one comparison, several distinct and possibly more diagnostic measures are implemented such as Weapons Usage, Doctrinal positioning, and the two types of control being considered here – spatial and temporal.

Parsimony To increase parsimony of the proposed analysis of control one would have to omit one of the measures or to combine them into one measure. Both have been shown to be applicable. History has shown that control of forces on the spatial battlefield is important, but no more important than control with respect to time. A simple example would be a small unit, offensively engaging in tactical ambush. Where the ambush takes place is critical. The enemy's movement needs to be restricted so that they cannot escape the kill zone. Excellent fields of fire and observation should be available to the attacking force. There should be cover and concealment for the force performing the ambush and there there should as much distance as possible between the force being ambushed and any possible reinforcements. However, none of these factors matters if the ambush is triggered too early, before the enemy reaches the kill zone, or too late, after much or all of the force has left the kill zone. Similarly, if the timing is perfect but the ambush position lacks several of the physical characteristics mentioned above, the ambush will probably fail. Spatial and temporal control of the forces are critical in nearly every battle and engagement. Too include both areas in a single measure would make the model ambiguous, too all-encompassing. Here two limited measures are of more diagnostic value than one comprehensive measure that cannot be separated.

Orthogonality The conceptual orthogonality of space and time should be intuitive. Parsimony and orthogonality often work together to separate and identify key concepts. Doctrinally, timing has been discussed as a different concept from positioning. A force does not necessarily show a high level of *spatial control* in a given time period simply because over time the arrangement of assets may show a great deal of *temporal control*. This will be more obvious with the explanation of how the models of spatial and temporal control are computed.

Modeling the Measures

Modeling Spatial Control Let spatial control be defined as, " the level of spatial organization exerted over the forces on the battlefield." Spatial organization refers to the combat power of the assets as they are arranged on the battlefield. Needed here is an objective and consistent method of quantifying the amount of organization that is evident. If the amount of combat power from each weapon system is calculated for each grid square (a size yet to be determined), and the units of combat power are summed for each square, the result is a three-dimensional space of grid (first two dimensions) and cumulative combat power (third dimension). If overlapping the combat power areas of each weapon represents the spatial control exerted over the assets, an indicator that reflects how mountainous the response surface is would be a good model for this measure.

Entropy is defined in the dictionary [Am Heritage 85] as "A measure of the disorder in a system ..." In Tribus [Tribus 69] the formula for calculating

the entropy of a system is given as:

$$S = \sum_{i} [P_i * \log P_i]$$

where:

S is the value of the measure of entropy for a system.

P_i is the probability that the system is in state i.

If entropy is a measure of disorder, then it is also a measure of a lack of order or lack of control. Decreasing entropy indicates control is increasing. An entropy calculation for the amount of spatial control would yield a value for a certain time period. A spatial control value for the entire battle would necessarily average all of the individual spatial control values for each time period.

In developing this model of control, the first decision the modeler must make is the granularity or the size of the grids and time increments. The size of the time increments affects only the amount of computation necessary and the fidelity of the control averages. Based upon the data available and the flow of the battles that will be analyzed, a five-minute time increment appears to be the most appropriate. Very few changes in combat power potential occur inside of 5 minutes and yet some of the small unit battles last only 15 or 20 minutes, thus making a larger time increment too insensitive. Both Nelson [Nelson 92] and Lamont [Lamont 92] used the 5-minute increment in their research. The measure may be limited somewhat by the time periods recorded in the NTC database. Some battles have the positions

recorded every 5 minutes while other battles are longer and the managers of the database decided to save positions every 20 minutes.

The grid sizes are more critical than the time increments. In fact, one may obtain a variety of entropy scores from one configuration of combat power by varying the grid size. Figure 3.9 shows a configuration of combat power. The numbers represent both the position and the relative combat power of friendly assets. In Figure 3.9, the smallest cell used for entropy calculations contains all of the combat assets. The entropy value is zero. The assets are concentrated as much as can be detected given the granularity. In Figure 3.10, the granularity is smaller and the entropy of this same configuration is now 0.693. Half of the friendly assets (200+300) are in the lower left-hand grid and half are in the upper right-hand grid. The smallest granularity is shown in Figure 3.11 where every asset is located in a different grid. The entropy value given this granularity is 1.280. Clearly, the spacing between assets is the same in all three cases, and the effect of the granularity is significant. Therefore granularity *is* important and should be chosen judiciously, to maximize the amount of information made available to the analyst. Also, once decided, the grid size should not be changed during the battle. Consistency within the battle and between battles is important for comparisons between units. A grid size of $100m \times 100m$ should allow enough information to be gathered and analyzed without causing artificial increases in the entropy. This grid size was selected due to the unit being examined (battalion and below) and the terrain database which has readings every 100 meters.

Spatial control is one of the two measures developed for the component control which indicates the level of control exerted over the forces on the

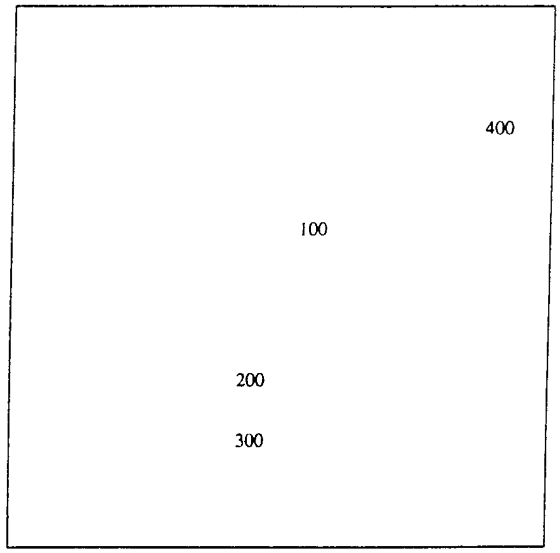


Figure 3.9: Example 1: Granularity vs. Entropy

battlefield. The spatial control value is an average of the spatial control computed for each of T time snapshots of the positioning of combat power. Its formula, or method of calculation, is:

$$SC = (\frac{-1}{T}) \sum_{t=0}^{T} \sum_{x=x_0}^{X} \sum_{y=y_o}^{Y} p_{xyt} * \log p_{xyt}$$

To normalize the spatial control value, the following calculation is proposed:

$$SC_{Norm} = \frac{S_{max} - SC}{S_{max} - S_{min}}$$

where:

SC is the spatial entropy value.

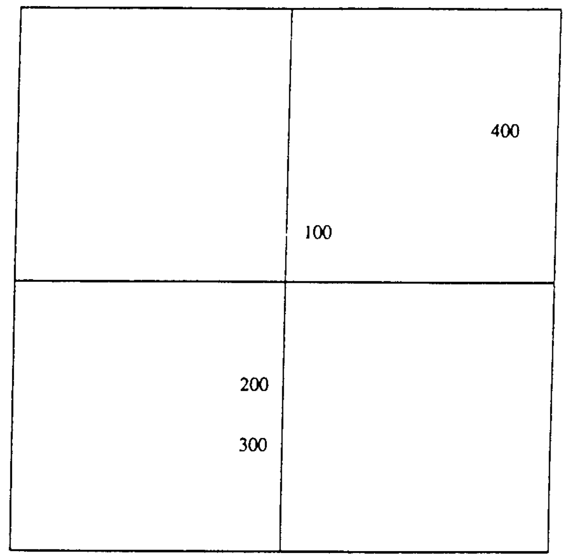


Figure 3.10: Example 2: Granularity vs. Entropy

SC_{Norm} is the spatial control measure's value.

p_{xyt} is the ratio $\frac{CbtPwr_{xyt}}{CbtPwr_{tot_t}}$

T is the number of time units being considered in the battle.

X is the width of area of interest

Y is the length of the area of interest.

S_{max}, S_{min} are the theoretical maximum and minimum (respectively) spatial entropy values that are possible given the weapon systems available.

Four figures of contrived configurations of battlefield assets are presented to illustrate the intuitive nature of the spatial control measure. In Figure 3.12, Configuration I shows five circles which represent the area covered

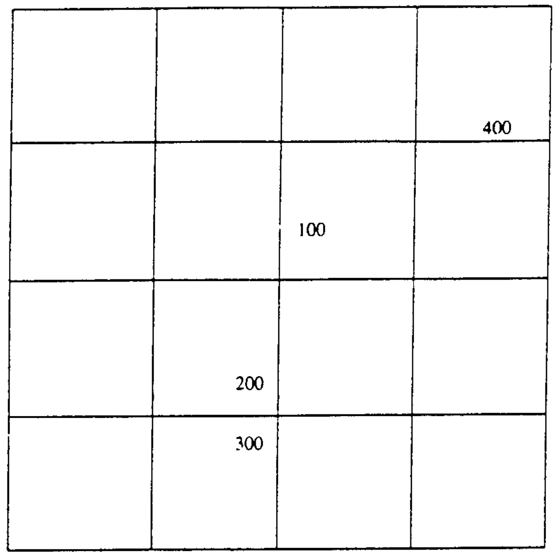


Figure 3.11: Example 3: Granularity vs. Entropy

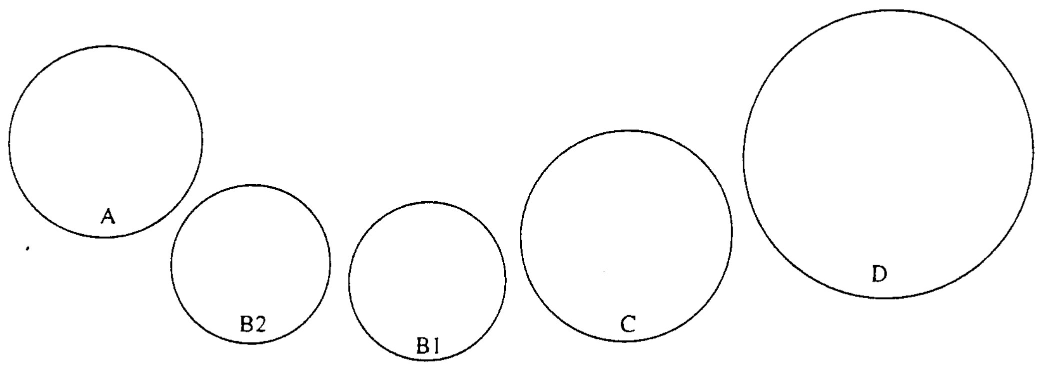
by five different weapons. In this case, for simplicity, the combat power density is assumed to be equal for each weapon system. The OLI of each weapon system is equal to the density multiplied by the area of the circled region. The area, in this case is proportional to the OLI which is proportional to the square of the radius. The following OLI values have been assigned to the various weapons:

A has OLI 324

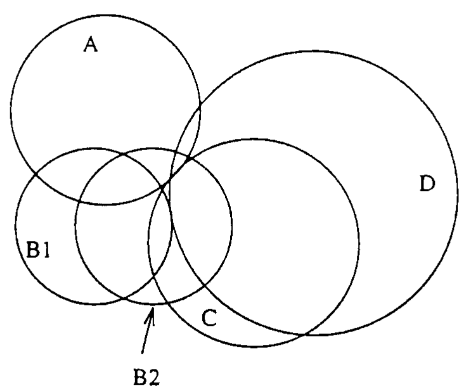
B1 has OLI 256

B2 has OLI 256

C has OLI 400

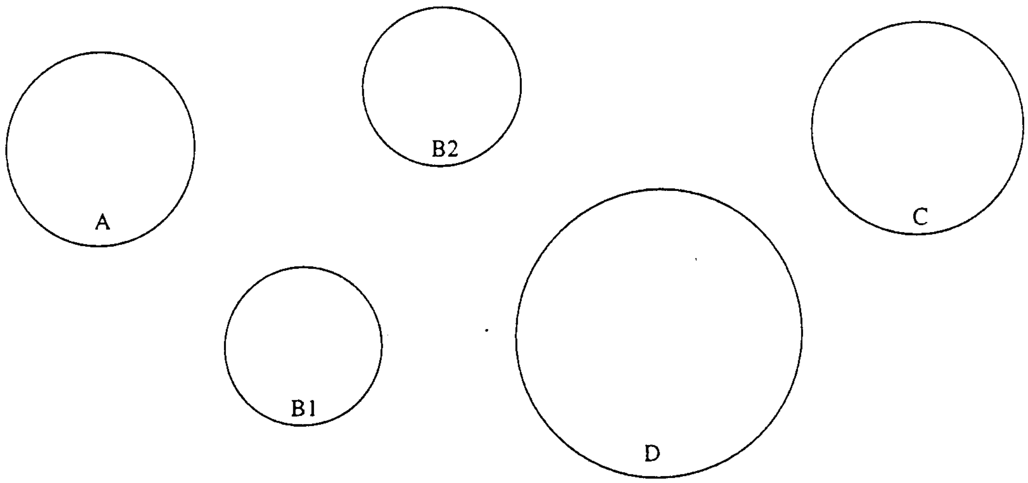


Configuration I

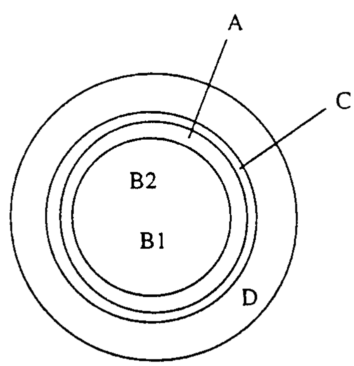


Configuration II

Figure 3.12: Examples (Configurations I & II) used for Spatial Control



Configuration III



Configuration IV

Figure 3.13: Examples (Configurations III & IV) used for Spatial Control

Table 3.3: Spatial Control Measure calculations

Configuration Number	Cbt Power Density 100	200	300	400	500	Spatial Control
I	2048.5	0	0	0	0	3.311
II	936.2	418	92.4	0	0	3.124
III	2048.5	0	0	0	0	3.311
IV	412.5	76	68	0	256	2.805

D has OLI 812.5

The same five weapon systems have been arranged in four different configurations. Configuration I has the weapons arranged linearly. Configuration II has them arranged so that there is some significant overlap among the weapons range circles. Configuration III depicts what could be a random placement. Configuration IV depicts the arrangement that has the most overlap possible among all of the systems.

The density of each of the circles with no overlap is 100 units per grid square. Assume the densities are additive so that in the areas with two overlapping circles, the density is 200; three overlapping circles, the density is 300, etc. Using the area of each circle already given as representing the number of grid squares contained in the region, Table 3.3 shows the areas of each density for each configuration.

Normalization Because the minimum entropy value with these particular weapons is 2.805 (maximum overlap), and the maximum value is 3.311 (no overlap), the spatial control value must be:

$$2.805 \leq SC \leq 3.311$$

Normalizing the score:

$$SC_{Norm} = \frac{SC_{max} - SC}{SC_{max} - SC_{min}}$$

In the case of configuration II, the normalized spatial control value is

$$SC_{norm} = (3.311 - 3.124)/(3.311 - 2.805) = 0.370$$

Such calculations are performed for every battle so that the final normalized spatial control value is forced between 0 and 1.

Modeling Temporal Control Using much of the same logic as that used in modeling spatial control, the temporal control measure should measure how combat power levels change with time. This concept is less intuitive but just as important. If a certain configuration for the combat assets is determined at time t_0, the same configuration may not be as appropriate at time t_1 or t_2. Both enemy and friendly forces are constantly acting and reacting as the situation changes. A high degree of temporal control would be reflected by the level of combat power in a given grid square changing significantly over time. No attempt is made to determine whether such a change is intrinsically good or bad. That evaluation will be made using other measures. Certainly, if a good configuration for combat assets is found and the enemy fails to react to this configuration (i.e., escaping or circumventing), keeping the same configuration would be appropriate. The temporal control value would be low for such a situation but would be easily justifiable.

The score, deriving its basic form from the spatial control formula, is an average of the control of combat power computed for each of the grids over the duration of the battle. Its formula, or method of calculation, is:

$$(\frac{-1}{X * Y}) \sum_{x=x_0}^{X} \sum_{y=y_o}^{Y} \sum_{t=0}^{T} p_{xyt} * \log p_{xyt}$$

where:

p_{xyt} is the ratio $\frac{CbtPwr_{xyt}}{CbtPwr_{Tot_{xy}}}$

T is the number of time units being considered in the battle.

X is the width of area of interest

Y is the length of the area of interest.

Criteria for Modeling

Parsimony The spatial and temporal control models are parsimonious in that they utilize only the data that directly measure the applicable concepts of combat power, position, and time. The model utilizes a well-known algorithm for measuring organization. It is intuitive in its intent, even if its mathematics are not as intuitive. There are no extra terms added to add a bit more realism. There are no terms that could be committed without significantly altering the value of the model.

Generalizability The grid squares have been chosen so that there are enough summands included in the computation of the averages to ensure robustness. There are 40,000 grid squares in a typical 10km X 40km battlefield. The average battle last between 2 and 6 hours which means there are between 25 and 73 time increments to improve the robustness. Because the

combat power measure includes so many attributes of the weapon systems, the models should be valid over many types of battles and involving many types of units.

Fidelity There is no existing data which could be used to test the fidelity. In Chapter Four, we will use existing databases and the opinions of several experts to check the doctrinal fidelity of this measure. Analytical validation has already been addressed during the building of the model.

Normalization Temporal control is normalized by calculating the maximum possible entropy that could have been achieved given the granularity of the time intervals used to calculate the entropy. For the final averaging, the grids are each weighted proportionally to the amount of combat power that was present in that grid cell over the entire duration of the battle.

3.6.3 Measures for Doctrinal Positioning

Doctrine provides some guidelines to help the commander identify the decisive point. On the offense, one normally wants to break the enemy's defense at the weakest point, thus accomplishing the immediate task of breaking through the defensive lines while minimizing friendly casualties. On the defense, the defending unit plans to mass its combat power on the place or places of the enemy's main attack.

Defensive doctrine would call for finding the point at which the enemy will concentrate the majority of its combat power-producing equipment and personnel. Offensive doctrine would recommend the main attack, thus the greatest concentration of combat power, at the weakest point of the enemy's

defensive position, whose breakthrough would still allow mission accomplishment. The weakest point would be defined as that location that has the least combat power available for destroying friendly forces. Due to terrain, and sometimes the weather, a piece of terrain will have little or no combat power assigned to it by the enemy for defensive purposes. Terrain and weather are sometimes enough to deter offensive actions. Clearly, we are now in the realm of game theory and strategy. If the attack position were known, the defense could be made much stronger at the known attack points. If the defensive strengths were known, attacking the weak point would similarly be much easier.

The purpose of the model is not prescriptive but diagnostic. This model is not to be used in selecting which areas to attack or which to defend more aggressively, but only to measure, once the battle has concluded, how well the leader and the unit conformed to published doctrinal guidelines. It does this by measuring how well the friendly force positioned its forces to maximize the number of enemy assets within the range of friendly combat power and minimize the number of friendly assets within the range of enemy combat power.

Proposed Measures

The following measures of doctrinal positioning are implied:

- Combat Power Projection
- Invulnerability

In both defense and offense, a subgoal which will assist the friendly force in accomplishing its mission is to:

- Minimize vulnerability

- Maximize combat power projection

Though the priority of the two subgoals may (should) differ, the same two subgoals should be valid in both offense and defense.

Subcomponent Selection Criteria

Applicability Bretnor [Bretnor 69], a well known 20th century military critic and theorist, believes there are two essential elements of the process that have typically been left out of models. "They do not include the forces of the enemy *directly and explicitly* in their descriptive framework, and, emphasizing the positive aspects of war, they virtually exclude from consideration the central negative factor of vulnerability." As explained in more detail in Chapter 2, he advances the view that processes and relationships of war all have two things in common: Might and Vulnerability.

Dupuy [Dupuy 85] pg 36, concluded that vulnerability is an essential factor. Vulnerability is not a characteristic of a weapon system, nor of the relative size of the enemy force, but the result of a model that relates personnel strength, posture, terrain, relative firepower, and air superiority. Exposure is considered an added vulnerability in special situations. In this model, invulnerability is used as one of the measures of doctrinal positioning that takes into account posture and relative firepower (combat power vs. assets). Rather than attempting to model the terrain and all of the rules that guide a decision based upon terrain, it will be omitted and left as justification for positioning after the indicators are reported.

Vulnerability and might are also certainly applicable measures of significant concepts of battle. With respect to doctrinal positioning, combat power projection and invulnerability represent two of the main subgoals. The Operations manual [FM 100-5 93] states on page 9-1, "The defender ... maneuvers to gain local superiority at the point of decision" and on page 7-2, wth respect to the offense, "Concentration of any size force is also a vulnerability." Similarly, local superiority on the offense is well accepted as a critical part of positioning, as are vulnerability considerations on the defense. Both invulnerability and combat power projection are important to both the offense and defense.

Comprehensiveness Comprehensiveness is not claimed here. In many doctrinal manuals (e.g. [FM 25-101 90]), positioning is based upon the acronym METT-T which stands for:

- Mission
- Enemy
- Terrain
- Time
- Troops

Invulnerability and combat power projection represent considerations of time, enemy, and troops. The effect of the posture on the relationship between the two measures and upon their effect on the doctrinal positioning measure should appear in the two models that will eventually be built. one

for offense and one for defense. The last area of concern is terrain. Terrain is NOT accounted for in either the combat power projection or the invulnerability measures.

Parsimony Parsimony is the main reason for not including terrain as a measure. The diagnostic value gained from including a very complicated model of terrain and its correct doctrinal use in implementing a certain course of action is estimated to be relatively small. Any measure of the correct use of terrain would be subject to criticism based on fidelity – simply because there are differing views on how to use terrain. Objective diagnostic results indicating easily understood and non-judgemental positioning scores could be much more easily interpreted by a tactical expert than by trying to convince a tactical expert that the model has already considered his or her tactical expertise with respect to terrain.

Orthogonality Although the two subcomponents proposed represent sometimes conflicting characteristics of a given positioning of forces, they do also represent significantly different doctrinal concepts. Reducing vulnerability keeps the force viable, protected, and ready to participate in combat. Increasing combat power projection improves the force's chances of accomplishing the mission by allowing destruction of the enemy. Without having enemy assets within friendly combat power ranges, there can be no enemy destruction. One characteristic is aggressive while the other is based upon survival. Oddly, the passive, survival-based characteristic is the one most frequently addressed in planning for the offense. While the mission of attack assumes destroying the enemy, the course of action selected is often the

one that provides for minimum vulnerability while still accomplishing the mission.

Similarly, the aggressive characteristic of combat power projection is often the lead discriminator in selecting the style of defense. While stopping the enemy's advance and survival are assumed missions for the defense, the course of action chosen (i.e., the placement of forces along with supplemental and complementary positions) often depends upon which alternative leads the enemy into the best kill zone where the majority of friendly combat power is focused.

Because of similarity of weapons between the enemy and friendly forces, as well as a similarity of ranges, there must be a tradeoff between invulnerability and combat power projection. For example, consider two opposing armored vehicles that have the same range and similar ammunition. As soon as the enemy tank is within range and subject to friendly combat power projection, the friendly armored vehicle is also within range of the enemy vehicle, thus increasing its own vulnerability.

Measurability Because this pair of measures requires use of enemy asset and enemy combat power information, the measurability depends on more than just friendly actions. The data for the enemy at NTC is just as available as the friendly data, with the same precision. Although the position of enemy assets is the result of enemy actions, the measurement is actually of resources, assets, and the resultant combat power.

Combat Power Projection

The goal of this measure is to calculate how much friendly combat power potential (CPP) is projected upon enemy assets. The measures are normalized by the total amount of friendly combat power available and the total amount of enemy assets present on the battlefield. The multiplicative operation allows the values to be zero in grids where either the enemy assets or the friendly combat power is zero. The combat power projection for an entire battle is the average of the CPP values for each time period.

$$CPP = \frac{\sum_{t=0}^{T} \frac{\sum_{i=1}^{N} CPD_{tF_i} * OLI_{tE_i}}{CPD_{max_t} * OLI_{total}}}{T}$$

where:

CPD_{tF_i} is the amount of combat power available to the friendly commander in grid i at time t.

CPD_{max_t} is the maximum amount of combat power available to the friendly commander at any grid at time t, given the relative positioning of the friendly forces at time t.

OLI_{tE_i} is the OLI of enemy assets located in grid i at time t.

OLI_{total} is the total OLI of enemy assets involved in the battle.

T is the number of time units that the battle lasts.

Modeling Invulnerability

Proposed Variables for Invulnerability

The following measures are implied for Invulnerability:

- Friendly Combat Assets
- Enemy Combat Power

The goal of this measure is to calculate how much of the friendly combat assets are endangered by coincidence in time and space with the projection of combat power potential of the enemy. The measures in each grid are normalized by dividing by the maximum enemy combat power projected into any one grid which is totally dependent upon the disposition of the enemy's assets. The total amount of friendly assets present within range is also used for normalization. Friendly Invulnerability is closely related to enemy Combat Power Projection, as following relation shows:

$$IV_{Blue} = 1 - CPP_{Red}$$

Specifically, for the friendly forces,

$$IV = 1 - \frac{\sum_{t=0}^{T} \frac{\sum_{i=1}^{N} CPD_{tE_i} * OLI_{tF_i}}{CPD_{max_t} * OLI_{total}}}{T}$$

where:

IV is the invulnerability measure for the battle.

CPD_{tE_i} is the amount of combat power available to the enemy commander in grid i at time t.

CPD_{max_t} is the maximum amount of combat power available to the enemy commander at any grid at time t.

OLI_{tF_i} is the amount of friendly assets located in grid i at time t.

OLI_{total} is the total amount of friendly assets involved in the battle.

T is the number of time periods in the battle.

Criteria for Modeling

Parsimony The goal of IV (and CPP) is to find a suitable transformation for the available data that will give an appropriate indication of the invulnerability or combat power projection of the friendly force. The formulae described are quite parsimonious. They include the multiplication of two proportions that are easily calculable, summed over the entire grid, and then averaged over the duration of the battle. Because the total amount of combat power and the total sum of assets do not change over the battle, these two values were removed from within the summation and their product applied after the summation. A more parsimonious model could not be constructed that retained the fidelity of a model that includes both the enemy and friendly locations and times.

Generalizability The robustness of these measures lies in what was left out. With no terrain modeling, there are no terrain exceptions. Terrain will be taken into account, but not internal to the measure. The scope of the measure is limited, therefore the generalizability of the measure, within those limits, is increased. The normalization of the combat power and the

assets provide for use of this measure with many types of friendly and enemy units. Averaging over time negates the effect of doctrinally correct positioning during a short time of the battle. To receive a high value in both invulnerability and combat power projection, a unit must be constantly aware of the enemy's position, the capabilities of both sides' weapon systems, and the assets available. The multiplicative operation allows the values to be zero in grids where either the enemy projected combat power or the friendly combat power is zero.

Fidelity Fidelity can be logically argued based on the restricted definition of the two measures. The invulnerability value would not indicate the best positioning of friendly forces. It is strictly a measure of the level of combat risk into which the friendly forces are placed due to the positioning of these forces by the commander.

We make an intuitive appeal to the fidelity of these measures using the configurations of enemy and friendly assets shown in Figures 3.14 through 3.17. The placement of friendly forces in the figures is not implied to be good or bad. There is no knowledge of terrain, weather, visibility, vegetation, morale, or any other important factor that usually influences a commander when deciding upon the best position for his forces. Invulnerability was selected for this example but the calculations are similar for a CPP comparison. In Configuration I, as seen in Figure 3.14, the friendly tanks have relatively little danger of being killed. The friendly tanks have positioned themselves so that only a machine-gunner and a BMP can range them – no enemy tanks. The Invulnerability measure has a relatively large value, as shown in column 5, Table 3.4. In Configuration II, none of the enemy assets can project its

Table 3.4: Invulnerability Values for various configurations.

Configuration Number	OLI_{FrTot}	CPD_{max}	Enemy CPP Value	IV Value
I	120,000	400cell	0.1875	0.8125
II	120,000	400cell	0.0	1.0
III	120.000	400cell	1.0	0.0
IV	120,000	400cell	0.5	0.5

combat power onto any of the friendly assets. The multiplicative portion of the IV model forces the enemy's CPP value to be zero and the friendly IV value to be 1.0. In other words, this situation is the best a friendly force can achieve with respect to invulnerability. In Configuration III, the friendly forces are positioned at the location which has the highest density of enemy combat assets that can range them. This is the configuration which causes the most vulnerability. It should yield the lowest IV value possible – 0.0. The normalization of dividing by the maximum enemy combat power density forces such a position to yield a value of 1.0. In Configuration IV, both tanks can be fired on effectively by an enemy tank. However, no other systems can bring effective fire upon them. The invulnerability model gives this configuration a IV value of 0.5. If the friendly tanks continue, in Configuration IV, they will most certainly find themselves in a high vulnerability area where several systems can range them. The value would be expected to be lower than 0.5 but still greater than 0.0 since there are no areas in this region which equal the maximum density.

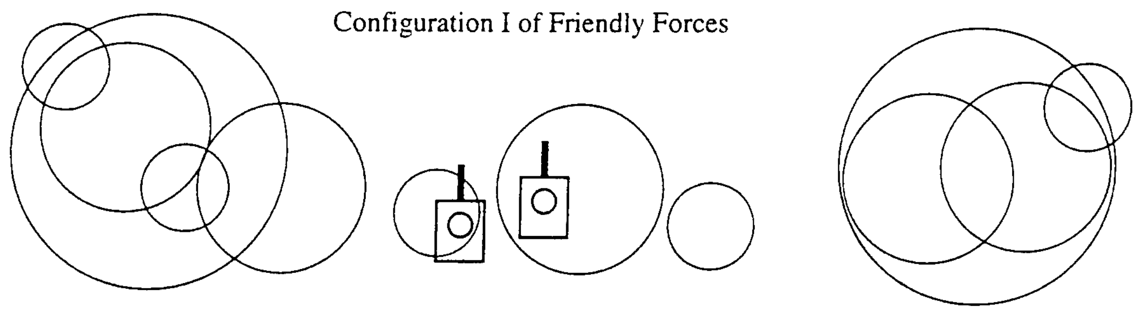


Figure 3.14: Configuration I of friendly assets to be used for invulnerability values.

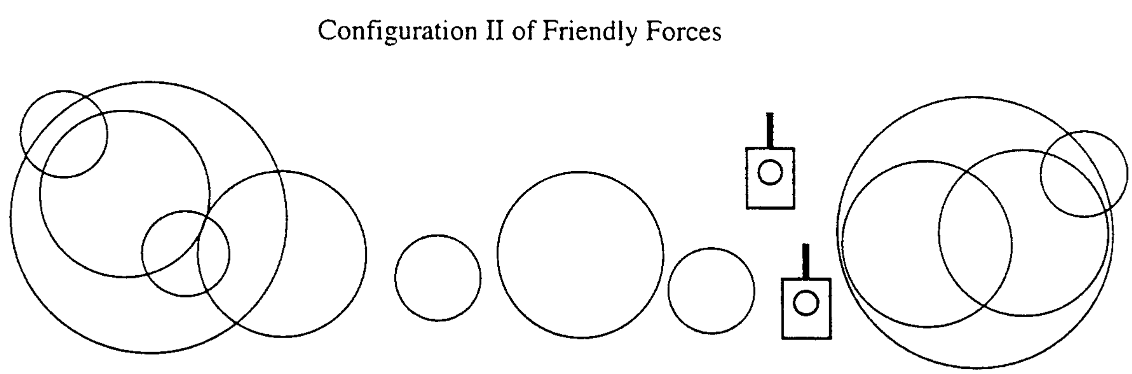


Figure 3.15: Configuration II of friendly assets to be used for invulnerability values.

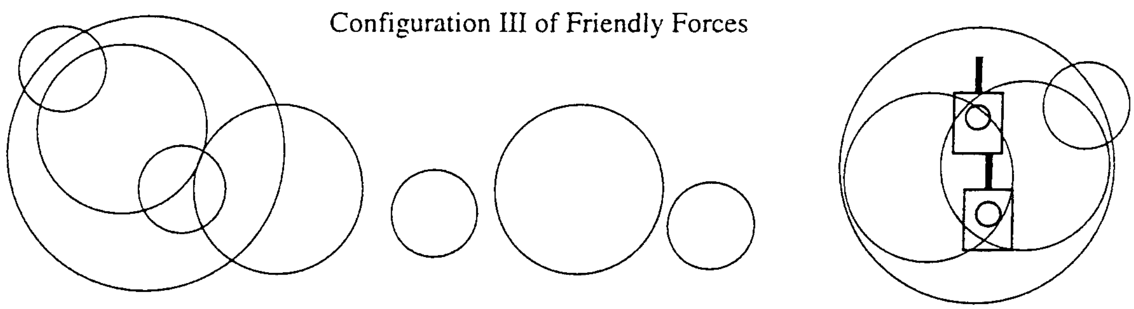


Figure 3.16: Configuration III of friendly assets to be used for invulnerability values.

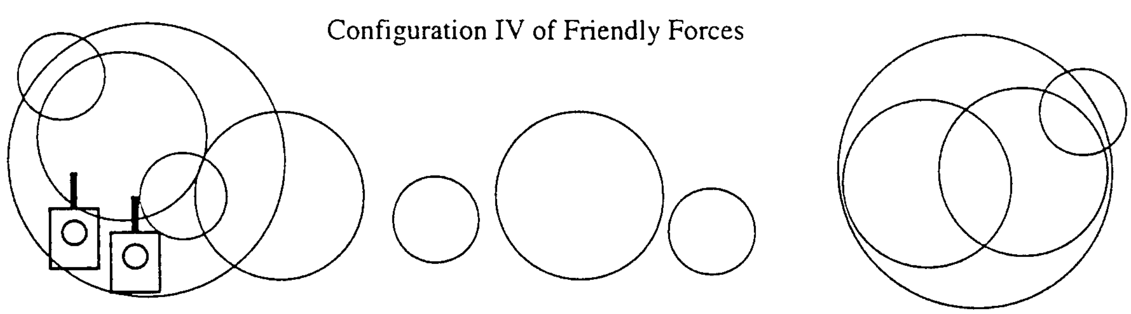


Figure 3.17: Configuration IV of friendly assets to be used for invulnerability values.

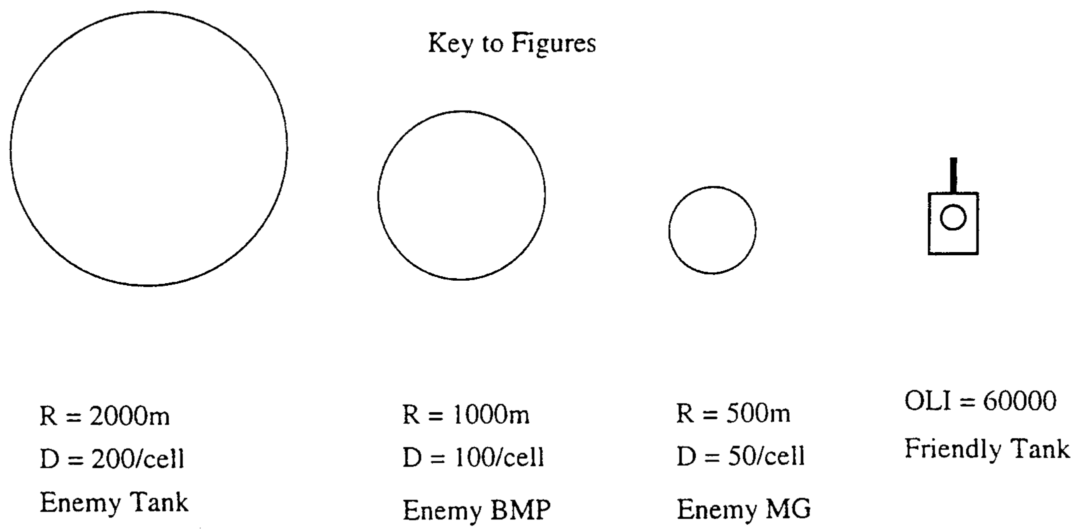


Figure 3.18: Key to Invulnerability Examples

3.6.4 Measures for Weapons Usage

Proposed Subcomponents

Weapons Usage, like Combined Arms Balance, relates directly to the actual firing and use of available combat power. BOSs are the most logical subcomponents that will allow measurement and provide a structure for it. The BOSs that are applicable, as supported by TRADOC and the staff at the NTC, are those that help destroy the enemy. The four proposed subcomponents are:

- Maneuver
- Fire Support
- Air Defense
- Mobility, Countermobility, and Survivability (MCMS)

Subcomponent Selection Criteria

Applicability A weapons usage value will give the commander an objective view of how much firing actually occurred for each BOS. He may wish to evaluate the weapons usage by unit or by weapon system. Using the measures developed here, he will know the amount of combat power produced by each type of weapon system. A battalion commander can use such diagnostic information more objectively than one broken down by unit. Although the BOSs that do not contribute directly to combat power can affect the outcome of the battle in many ways, they are not included in this set of subcomponents.

Comprehensiveness Each of the *weapon* systems on the battlefield is included in exactly one of the following four categories of weapons:

Maneuver includes all of the direct-fire weapons.

Fire Support includes all of the indirect-fire weapons.

Air Defense includes all missiles and guns whose primary purpose is air defense.

MCMS includes mines and minefields, obstacles, and defensive positions.

Parsimony The four categories were chosen so that each weapon system could be categorized by:

- The type of ammunition used
- The type of use of the weapon i.e., its purpose
- The commander or staff officer overseeing the tactical use and coordination of the weapon

These criteria helped form the four subcomponents. The direct-fire weapons are used in the close battle and under the complete control of the maneuver commander. The indirect-fire weapons use ammunition for area targets and are coordinated during the battle by the Fire Support Officer. The Air Defense Weapons, although not as numerous as the direct-fire weapons, are completely different. They are coordinated by the Air Defense Officer on the battalion staff, are used against enemy aircraft, and utilize completely

different ammunition and firing platforms. A separate category is needed for Air Defense. Finally, the MCMS involves mainly the combat engineers, coordinated and controlled by the Engineer officer, not usually found at battalion level but normally available from division when needed. He has the ability to increase combat power by stalling the enemy in a kill zone (countermobility), leading the enemy force into a kill zone (canalization), assisting friendly units through minefields, across bridges, or through tank traps (mobility), and building fighting positions (survivability). All of these affect the combat power directly either by decreasing the enemy's combat power or increasing that of friendly forces. At times, combat engineers fight immediately beside armored vehicles, infantry fighting vehicles, and dismounted infantry. A separate category is clearly needed for the engineers.

Orthogonality The weapons usage categories are orthogonal with respect to type of ammunition, purpose of the weapon, and the coordinator of the systems. The training community for the US Army developed this categorization because of its orthogonality and its practicality in diagnostics [FM 100-5 93].

Measurability The measures already defined in the combined arms measure will comprise necessary statistics for the measurement of weapons usage. The only new measurements that must be made are the calculations of total combat power used and available for Air Defense and for MCMS. These were not previously needed for the combined arms balance measure.

Modeling Weapons Usage

As with the combined arms measure of synchronization, weapons usage is normalized by the values of the individual weapon systems based upon the basic load and then weighting the BOS values by the importance of the included weapons systems. Since the normalization has already occurred for the calculation of the values for the combined arms measure, a simple weighted average of those values will yield a weapons usage value.

$$WU_{Total} = \frac{1}{CbtPwr_{Total}} * \sum_{i=1}^{5} BOS_i * CbtPwr_i$$

where:

WU_{Total} is the total Weapons Usage score for the battle.

$CbtPwr_{Total}$ is the total amount of combat power available in the unit.

BOS_i is the BOS value for the ith BOS.

$CbtPwr_i$ is the total combat power available to the unit from the ith combat arm.

NOTE: Air Support

Close air support (CAS) is a large contributor to the immediate ground war but air interdiction (AI) can also play a vital role. The number of sorties of each that are actually flown are recorded as well as the number sorties available. The number available, i.e., allocated by a higher commander, is considered the unit's 'basic load' for the battle. An unsolved problem is to measure the effectiveness of AI on the present battle. Often the effect is

felt in subsequent battles and is more meaningful at the division, corps. and theater level of combat. For battalion battles, a generic combat power value should be assigned to an air interdiction mission.

Criteria for Modeling

Parsimony Combat power used has already been calculated for two of the measures of the combined arms measure. The combat power. not the normalization of it, is needed to yield an accurate indicator of the weapons usage of the unit. Since every weapon system fires ammunition possessing its own associated specific combat power, if the usage value is normalized. the importance of that weapon system will be lost. Also. because there are different numbers of weapon systems, the total combat power controlled or affected by that weapon system will be lost if a normalized value is used instead of the actual combat power total for that weapon system category. For example, if a low overall weapon usage value is shown for the fire support category. ideally one would want to ascertain which part of the fire support system had very low usage or if it was a wide spread problem throughout the BOS. Diagnostically, the process of elimination is the tool of preference for locating the culprit weapon system. Parsimony supports keeping the level of inquiry near the top of the weapon system hierarchy. Usefulness and applicability tend to push the level to the bottom of the hierarchy. The level may be changed by different researchers depending upon the purpose of the inquiry. Only the BOS values will be immediately available and normalizable (the BOS values *are* the individual normalized weapons usage values).

Generalizability The weapons usage measure is generalizable over different postures, units, and classes of terrain. The normalization procedure accounts for different ammunition, numbers of weapon systems, and levels of ammunition supply. Not accounted for are varying levels of importance for each BOS in comparable battles. However, because this is an objective measure, the subjective importances assigned the weapons systems are not desired – they would bias the results and hurt the objectivity of the measure.

Fidelity The fidelity of this measure is found in its objectivity and in the fidelity of the combat power assigned to each round or unit of fire power. If that assignment is valid, the mathematics are very straight forward. The normalization techniques are classic and the aggregation method is Simple Additive Weighting. Although the assignment of the units of firepower is critical and based upon the OLI by Dupuy, any consistent combat power indicator can be interchanged with OLI without affecting the methodology used.

Synchronization Diagrams On the following two pages are diagrams which represent the structure of model of the tenet of synchronization. The diagrams separate the structure into two diagrams simply due to space restrictions. All four concepts, combined arms, control, weapons usage, and positioning, directly relate to the tenet of synchronization. Each of the lowest nodes is a measure that has been explained earlier in this chapter.

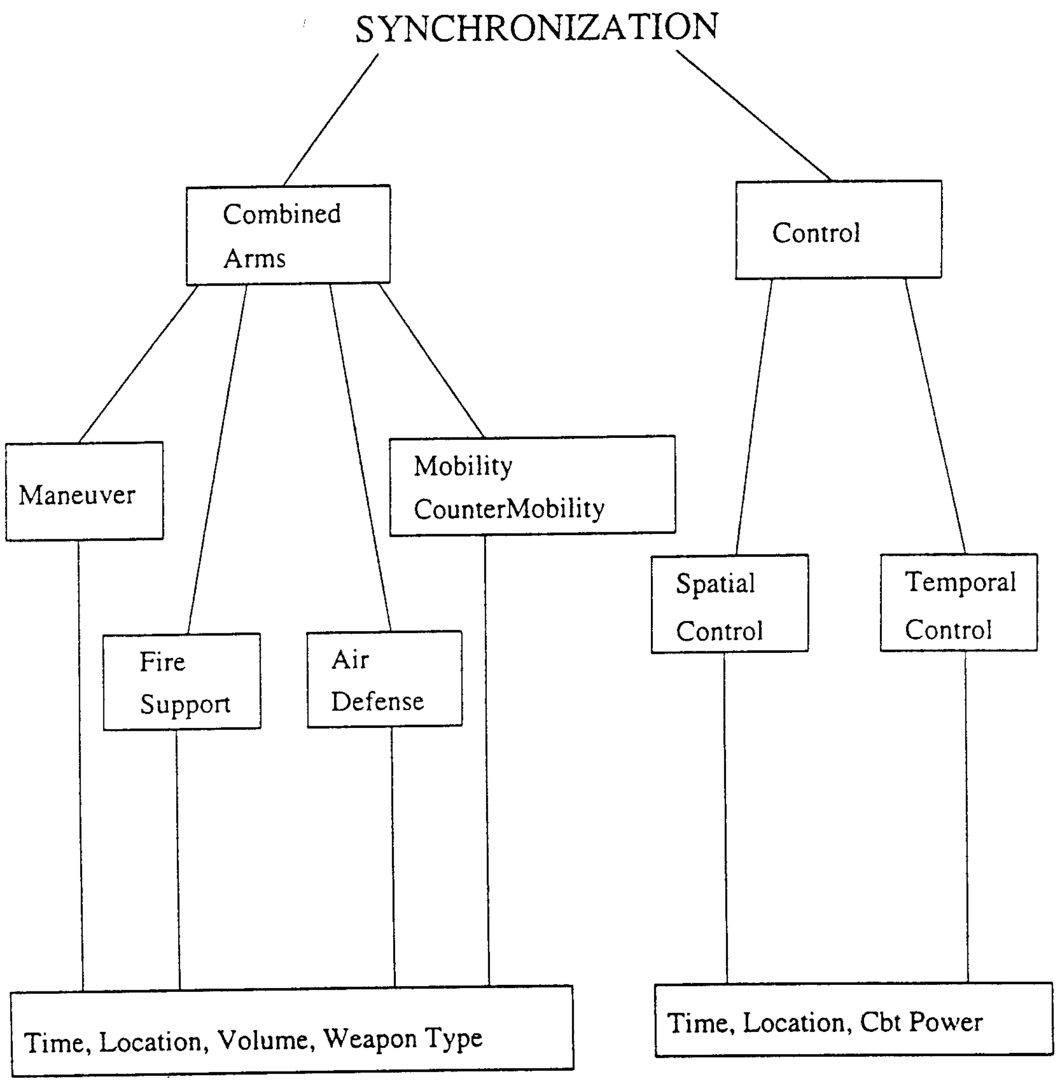


Figure 3.19: First Two Components of Synchronization

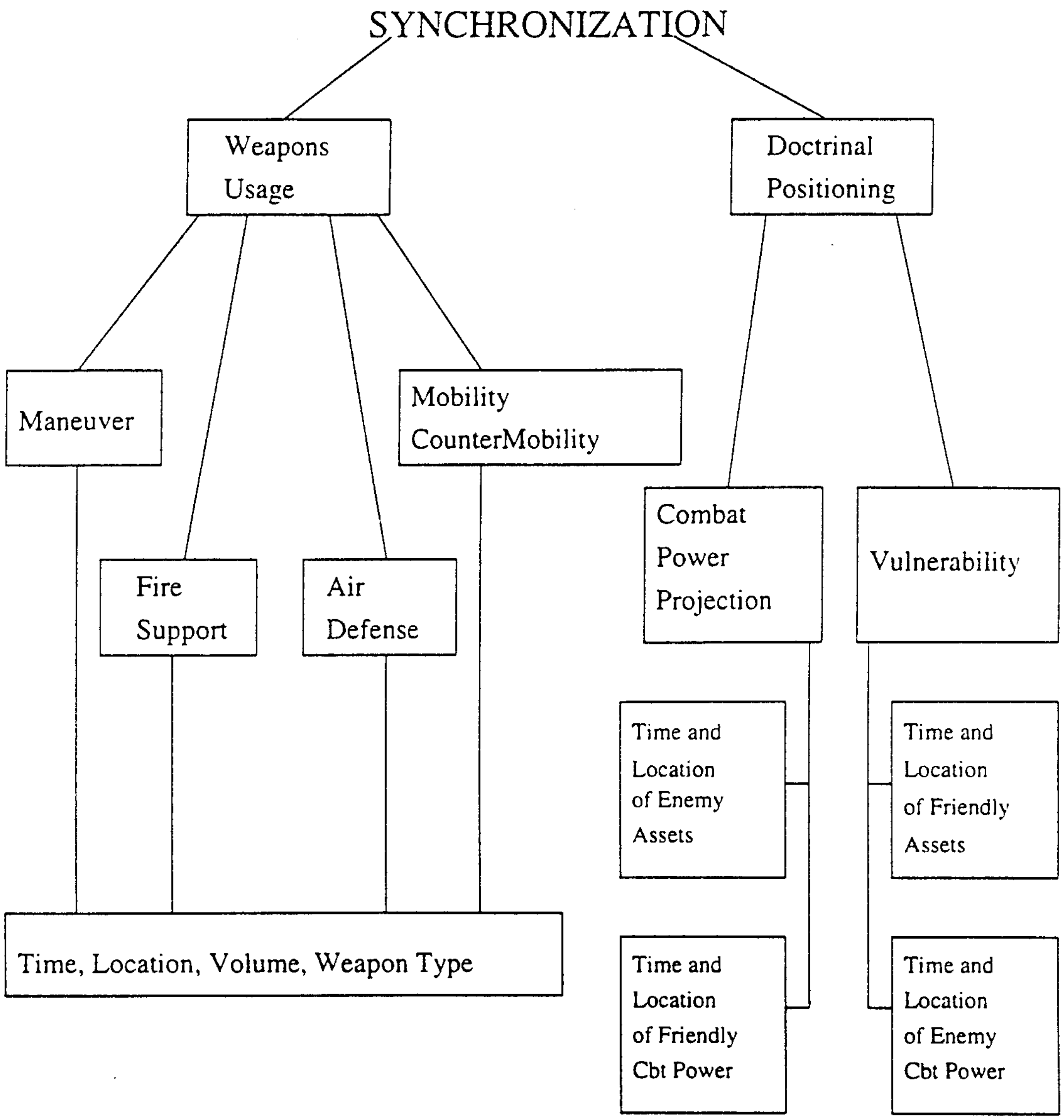


Figure 3.20: Second Two Components of Synchronization.

3.7 Summary of the Measures

In the following few pages is found a summary of the newly developed components and their measures. Each table includes the name of the measure, the component for which it is a metric, and the component's parent Tenet of Army Operations. A formula for each measure is presented with a short definition of the measure and how its mathematical formula relates observable data to the component.

Organizational Speed	
A Measure of Organizational Agility which is a Component of the Tenet of Agility. It is the normalized speed of the staff in issuing FRAGOs and the operations order (OPORD). The rule used to normalize the values is based on doctrinal guidance – $\frac{1}{3}$ of available time is used to publish, $\frac{2}{3}$ of available time is given to subordinate units.	$$OA_s = \frac{1}{2}\sum_{m=1}^{M}\frac{MIN[1, \frac{3}{2}(1 - T_{F_m})]}{M}$$ $$+\frac{1}{2}MIN[1, \frac{3}{2}(1 - T_O)]$$ $T_O = \frac{t_O}{T_{AO}}$ and $T_{F_m} = \frac{t_{Fm}}{T_{Am}}$ where: M is the number of FRAGOs published t_O is the time it takes to publish OPORD T_AO is the time available to publish OPORD T_O is the fraction of available time used to publish OPORD T_{AF_m} is the time available to publish FRAGO m t_{F_m} is the time it takes to publish FRAGO m T_{F_m} is the fraction of available time used to publish FRAGO m

Decision Making Speed	
A Measure of Mental Agility which is a Component of the Tenet of Agility. It is the average speed of the commander in making changes to the Operations Order. This is the only measure that has not been normalized.	$$MA_{speed} = \frac{N}{\sum_{n=1}^{N} T_n}$$ where: N is the number of OPORD changes; T_n is the time to make decision on change n

Maneuver	
A Measure of the manifestation of Physical Agility which is a Component of the Tenet of Agility. It is the sum of the combat power moved, weighted by the ratio of actual speed to maximum speed and normalized by total combat power.	$$Maneuver = \frac{\sum_{j=1}^{J} \frac{P_j}{S_j} \frac{\sum_{k=1}^{K} D_{jk}}{\sum_{k=1}^{K} T_{jk}}}{\sum_{j=1}^{J} P_j}$$ where: P_j is the combat power of weapon system j; J is the number of weapon systems in the unit; K is the number of moves made by the unit.; T_{jk} is the time for the kth move with jth weapon; D_{jk} is the distance of move k by weapon j

Maneuver BOS	
A Measure of the Maneuver Subcomponent of Combined Arms and Weapons Usage which are Components of the Tenet of Synchronization. It is the total amount of combat power used that originated from a weapon considered a maneuver asset.	$$Maneuver = \frac{1}{CbtPwr_{Maneuver}} * \sum_{i=1}^{I} V_i * CbtPwr_{rd_i}$$ where: $Maneuver$ is the Maneuver (Direct-Fire) BOS value. $CbtPwr_{Maneuver}$ is the total combat power available from every maneuver asset basic load. V_i is the # of rounds fired from the ith weapon. $CbtPwr_{rd_i}$ is the combat power in 1 round from weapon system i.

Fire Support BOS

A Measure of the Fire Support Subcomponent of Combined Arms and Weapons Usage which are Components of the Tenet of Synchronization.

It is the total amount of combat power used that originated from a weapon considered a fire support asset. Included are mortars, artillery, MLRS, naval gunfire, and air support.

$$FS = \frac{1}{CbtPwr_{FS}} * \sum_{i=1}^{I} V_i * CbtPwr_{rd_i}$$

where:

FS is the Fire Support BOS value.

$CbtPwr_{FS}$ is the total combat power available from every Fire Spt asset basic load.

V_i is the # of rounds fired from the ith weapon.

$CbtPwr_{rd_i}$ is the combat power in 1 round from weapon system i.

Air Defense BOS

A Measure of the Air Defense Subcomponent of Combined Arms and Weapons Usage which are Components of the Tenet of Synchronization.

It is the average percent of friendly forces, including combat, combat support, and combat service support units, that were adequately covered by air defense assets.

$$AD = \frac{1}{T} * \sum_{t=1}^{T} \frac{CbtPwr_{cov_t}}{CbtPwr_{tot_t}}$$

where:

AD is the Air Defense BOS value.

T is the number of time periods in the battle.

$CbtPwr_{cov_t}$ is the combat power adequately covered at time t.

$CbtPwr_{tot_t}$ is the total friendly combat power at time t.

MCMS – Defense BOS

A Measure of the MCMS (Def) Subcomponent of Combined Arms and Weapons Usage which are Components of the Tenet of Synchronization.

It is the weighted sum of the ratios of countermobility and survivability effort in four main areas over the total amount of possible effort as measured by the engineering hours and equipment available.

$$MCS_{Def} = K1 * A + K2 * B + K3 * C + K4 * D$$

where:

$K1 + K2 + K3 + K4 = 1$

MCS_{Def} is the value for countermobility and survivability in the defense.

A is the percent of mines actually laid.

B is the percent of primary positions dug.

C is the percent of supplementary positions dug.

D is the percent completion of obstacles, other than mines, that were planned.

$K1 - K4$ are weighting constants, initally set at .25.

MCMS – Offense BOS

$$MCS_{Off} = \frac{\sum_{i=1}^{N} \frac{EVAL_i}{Max_i}}{N}$$

A Measure of the MCMS (Off) Subcomponent Combined Arms and Weapons Usage which are Components of the Tenet of Synchronization.

It is the average ratio of mobility and countermobility efforts at identified sites over the total amount of possible effort as measured by the engineering hours and equipment available.

where:

MCS_{Off} is the value for mobility/countermobility in the offense.

N is the No. of mobility problems encountered.

$EVAL_i$ is an evaluation of the equipment hours used at each site of a mobility task.

Max_i is the estimated maximum number of equipment hours available at each site.

Combined Arms Balance

$$CA_{tot} = \frac{\sum_{i=1}^{4} [BOS_i - BOS_{avg}]^2}{4}$$

A Measure which combines the BOS measures to indicate the level of Combined Arms which is a Component of the Tenet of Synchronization.

It is measure of the balance of the effort reflected by the variation of the four normalized BOS values.

where:

CA_{tot} is the value for combined arms use.

BOS_i is the normalized value for the ith BOS.

BOS_{avg} is the average of the four BOS_i values.

Spatial Control	
A Measure of the Spatial Subcomponent of Control which is a Component of the Tenet of Synchronization. It is the entropy calculation of density of combat power with respect to a two-dimensional battlefield and then averaged over time.	$$SC = (\frac{-1}{X*Y*T})\sum_{t=0}^{T}\sum_{x=x_0}^{X}\sum_{y=y_o}^{Y} p_{xyt} * \log p_{xyt}$$ where: SC is the spatial control value. p_{xyt} is the ratio $\frac{CbtPwr_{xyt}}{CbtPwr_{Tot_t}}$. T is the number of time units in the battle. X is the width of the area of interest. Y is the length of the area of interest. $CbtPwr_{tot_t}$ is the total combat power at time t.

Temporal Control	
A Measure of the Temporal Subcomponent of Control which is a Component of the Tenet of Synchronization. It is the entropy calculation of density of combat power with respect to time and a given grid, averaged over the total area.	$$TC = (\frac{-1}{X*Y*T})\sum_{x=x_0}^{X}\sum_{y=y_0}^{Y}\sum_{t=0}^{T} p_{xyt} * \log p_{xyt}$$ where: TC is the temporal control value. p_{xyt} is the ratio $\frac{CbtPwr_{xyt}}{CbtPwr_{Tot_{xy}}}$ $CbtPwr_{Tot_{xy}}$ is the combat power in grid xy, summed over time.

Combat Power Projection

A Measure of the CPP Subcomponent of Doctrinal Positioning which is a Component of the Tenet of Synchronization.

It is the time-averaged calculation of the overlap of friendly offensive combat influence and the positions of the enemy assets. It is normalized by the total enemy assets and the total friendly combat power.

$$CPP = \frac{\sum_{t=0}^{T} \frac{\sum_{i=1}^{N} CPD_{tF_i} * OLI_{tE_i}}{CPD_{max} * OLI_{total}}}{T}$$

where:

CPP is the Combat Power Projection value.

CPD_{tF_i} is the combat power available to the friendly commander in grid i at time t.

CPD_{max_t} is the maximum available friendly combat power in any grid at time t, given the location of the forces.

OLI_{tE_i} is the enemy OLI in grid i at time t.

OLI_{total} is the total enemy OLI.

Invulnerability

A Measure of the Invulnerability Subcomponent of Doctrinal Positioning which is a Component of the Tenet of Synchronization.

It is the time-averaged calculation of the overlap of enemy offensive combat influence and the positions of friendly assets. It is normalized by the total amount of friendly assets and the maximum enemy combat power density in any one grid.

$$IV = \frac{\sum_{t=0}^{T} \frac{\sum_{i=1}^{N} CPD_{tE_i} * OLI_{tF_i}}{CPD_{max} * OLI_{total}}}{T}$$

where:

IV is the Invulnerability value.

CPD_{tE_i} is the amount of combat power available to the enemy commander in grid i at time t.

CPD_{max_t} is the maximum density of combat power available to the enemy commander at any grid at time t.

OLI_{tF_i} is the amount of friendly assets located in grid i at time t.

OLI_{total} is the total amount of friendly assets involved in the battle.

T is the number of time periods in the battle.

Weapons Usage

A combination of the BOS Measures to Measure the Weapons Usage Component of the Tenet of Synchronization.

It is the weighted mean of the combat power values for each battlefield operating system. The weighting depends upon the percent of the total combat power contained in each battlefield operating system and represents the actual combat power used.

$$WU_{Total} = \frac{1}{CbtPwr_{Total}} * \sum_{i=1}^{4} CA_i * CbtPwr_i$$

where:

WU_{Tot} is the Weapons Usage value.

$CbtPwr_{Tot}$ is the total unit combat power available.

BOS_i is the ith BOS value.

$CbtPwr_i$ is the total unit combat power from the ith BOS.

3.8 Example

It should be helpful to see how the previously described measures are calculated for a small, hypothetical battle. The purpose of this example battle is show exactly how each measure is calculated from data that is currently available from the NTC database. The figures in the example should also be instructional for readers who might be unfamiliar with actual, training, or simulated battles at any level.

3.8.1 Scenario

This example takes place in navigable terrain that is fairly flat with a few rolling hills. There are patches of vegetation that can reach 10 feet tall. The friendly force (B) and the opposing force (O) have the platforms listed in Table 3.5.

Table 3.5: Example Platform File

LPN	Side (B/O)	Range (meters)	OLI	Max Speed	Description
S1	O	3000	103	6	Sagger Anti-tank Missile
S2	O	3000	103	6	Sagger Anti-tank Missile
T1	O	2100	625	80	T72 Main Battle Tank
T2	O	2100	625	80	T72 Main Battle Tank
B1	O	1000	245	80	BMP Armored Pers Carrier
B2	O	1000	245	80	BMP Armored Pers Carrier
AD	B	3000	14	6	Stinger Air Defense Missile
How	B	14600	402	56	M109A2 155mm Howitzer
IFV	B	2500	746	66	Inf. Fighting Vehicle
TOW	B	3750	195	64	Anti-tank wire-guided missile
M1	B	3500	712	67	M1 Abrahms Main Tank

LPN stands for logical player number. In this example, the LPN is also the label for each of the platforms in the battle figures. The **Side** is either O for opposing forces or **B** for the blue or friendly forces. **Range** is how far the weapon system is effective against other weapon systems. The **OLI** is the number that represents each platform's relative worth on the battlefield [Dupuy 85]. **Max Speed** is the maximum road speed in kilometers per hour for that particular platform.

The friendly force has five platforms and the opposing force has six. The opposing force has found some terrain that is suitable for defending and has been given the mission of defending the upper left-hand region of the area in Figure 3.7.1. The friendly force has been tasked with finding and destroying the enemy. The circles in Figures 3.21 – 3.22 have radii equal to the ranges of the respective platforms shown in the above table.

Proceeding through the battle, each figure represents a snapshot in 15-minute intervals. The entire battle lasts 1.25 hours. (Typically a battle at the National Training Center will last from 2 to 6 hours and the database contains entries for intervals from 5 to 20 minutes.)

In Figure 3.21 there is no contact. None of the direct-fire weapons are within firing range of any of the opposing force's weapon systems. The range of the howitzer (HOW), which is an indirect-fire weapon, is potentially effective in the grid square that contains an enemy anti-tank weapon (S1). Figure 3.22 shows the armored personnel carrier (IFV) proceeding into range of the enemy weapons. The enemy platforms, which carry enemy weapons, did not change their positions. (Even on defense, there would probably be some movement by the enemy forces, but for this example they remain in their original positions.) Figure 3.23 shows a destroyed IFV for the friendly

force. Within the same fifteen minutes, the remainder of the friendly force (except for the howitzer) changes direction and heads south to avoid the apparent 'kill zone' in which the IFV was caught.

Figure 3.24 shows the friendly force preparing to attack from the south. Several friendly platforms have weapons that can fire on the anti–tank platform that killed the IFV. However, no opposing force can yet fire on any of the friendly platforms. Figure 3.25 indicates further movement by the friendly force into the opposing force's area. Both sides now have assets that are within range of the other force's assets. A firefight ensues. Figure 3.26 shows the results of the fire-fight with one additional friendly platform (AD) destroyed and three additional opposing force platforms (T1, B1, and S1) destroyed. The other three opposing force assets are within range of at least two of the three remaining friendly platforms' weapons while no friendly asset is within an opposing force's range circle. The battle is over and the friendly force's mission has been accomplished.

3.8.2 Collected Data

If this had been an actual training battle, tables of data would have been produced by the actions that occurred during the battle. Each of the four tables that follow are indicative of the data that are available for each battle fought at the NTC.

Table 3.6 gives the time period (**Time**), logical player number (**LPN**) and grid location (**X,Y**) of every enemy and friendly asset during the entire battle. A typical GPLT.NTC file used in the experiment in Chapter Four is about 20,000 lines long. It allows tracking of position, speed, coordination of assets, and distance between opposing platforms. For clarity, the platforms

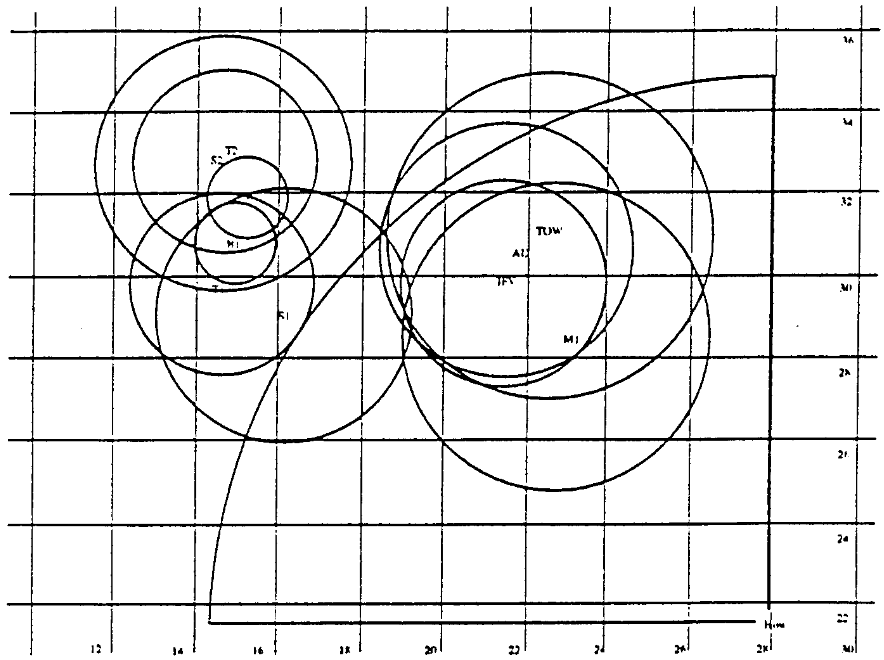


Figure 3.21: Battle configuration 1 at time = 0

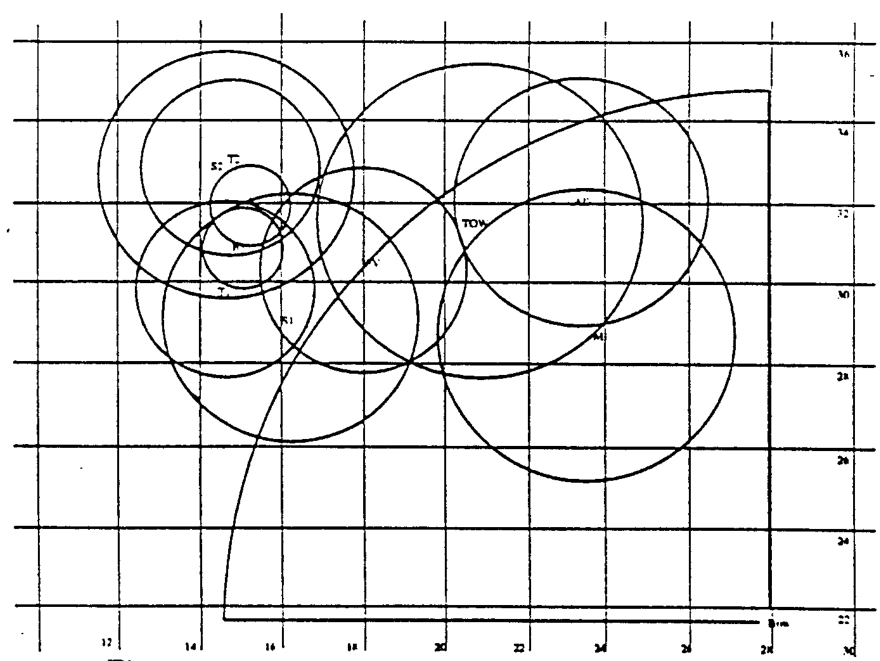


Figure 3.22: Battle configuration 2 at time = 15 min

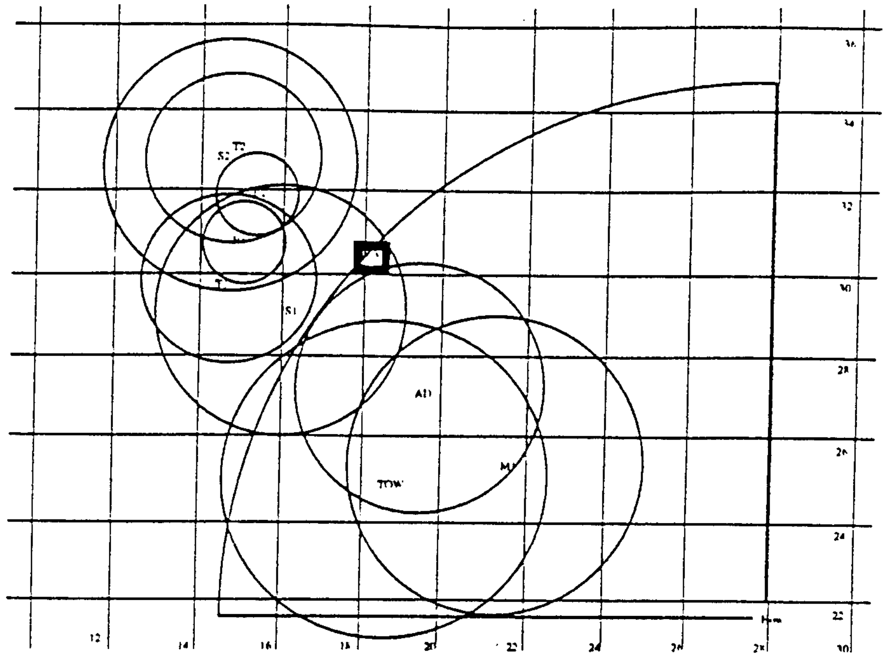


Figure 3.23: Battle configuration 3 at time = 30 min

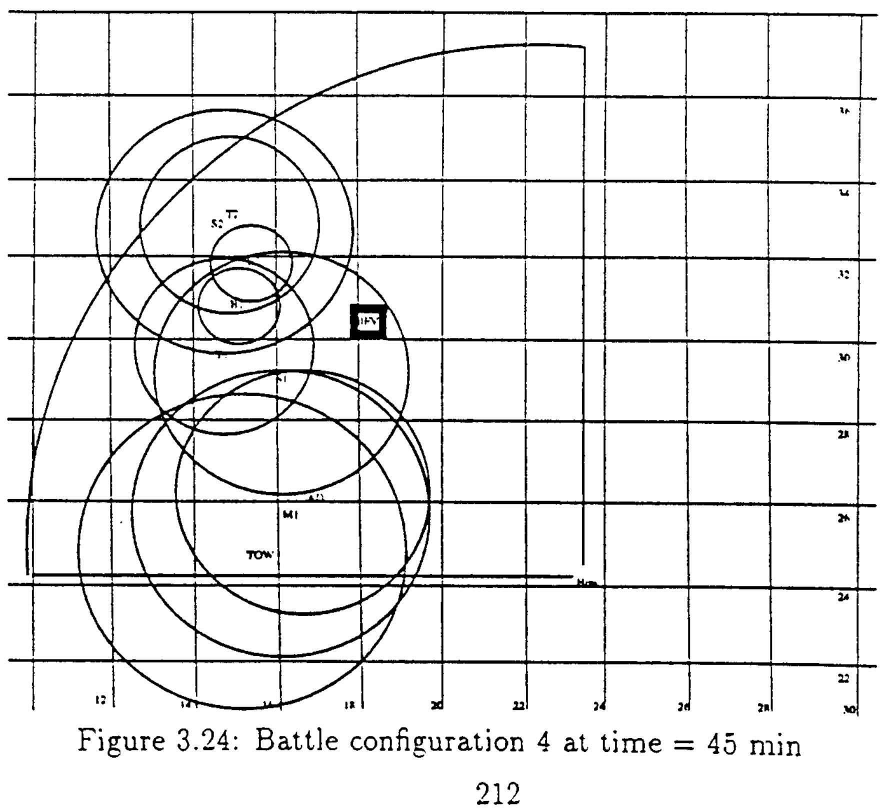


Figure 3.24: Battle configuration 4 at time = 45 min

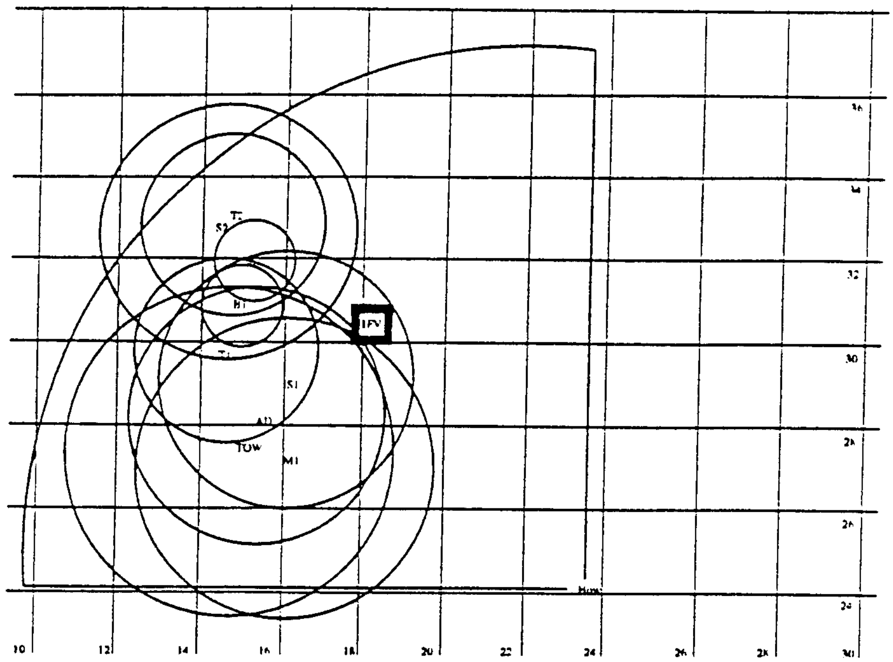


Figure 3.25: Battle configuration 5 at time = 60 min

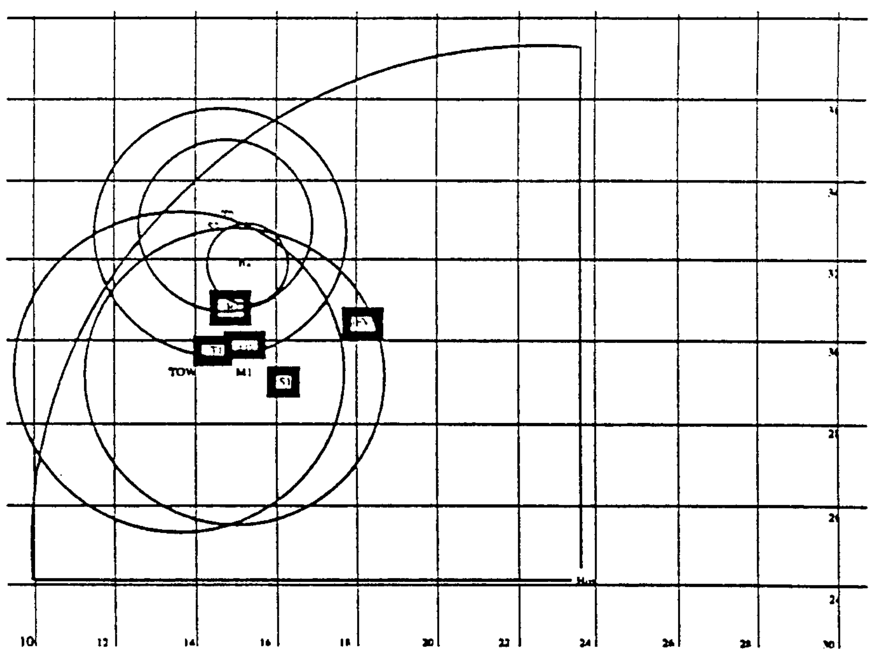


Figure 3.26: Battle configuration 6 at time = 1 hr 15 min

Table 3.6: Sample GPLT.NTC (location) Table

Time	LPN	X	Y	Time	LPN	X	Y
1	S1	162	288	4	S1	162	288
1	S2	145	329	4	S2	145	329
1	T1	147	297	4	T1	147	297
1	T2	149	331	4	T2	149	331
1	B1	145	309	4	B1	145	309
1	B2	154	320	4	B2	154	320
1	AD	220	306	4	AD	169	261
1	HOW	281	216	4	HOW	236	240
1	IFV	215	299	4	IFV	Dead	Dead
1	TOW	226	312	4	TOW	155	247
1	M1	232	285	4	M1	163	257
2	S1	162	288	5	S1	162	288
2	S2	145	329	5	S2	145	329
2	T1	147	297	5	T1	147	297
2	T2	149	331	5	T2	149	331
2	B1	145	309	5	B1	145	309
2	B2	154	320	5	B2	154	320
2	AD	234	320	5	AD	157	281
2	HOW	281	216	5	HOW	236	240
2	IFV	182	305	5	IFV	Dead	Dead
2	TOW	207	315	5	TOW	153	274
2	M1	240	286	5	M1	164	272
3	S1	162	288	6	S1	Dead	Dead
3	S2	145	329	6	S2	145	329
3	T1	147	297	6	T1	Dead	Dead
3	T2	149	331	6	T2	149	331
3	B1	145	309	6	B1	Dead	Dead
3	B2	154	320	6	B2	154	320
3	AD	196	271	6	AD	Dead	Dead
3	HOW	281	216	6	HOW	236	240
3	IFV	Dead	Dead	6	IFV	Dead	Dead
3	TOW	188	248	6	TOW	138	292
3	M1	218	253	6	M1	154	292

that have been destroyed are listed as 'dead'. In the actual files the LPN simply does not appear in future time periods after the system has been destroyed.

Table 3.7 is an example of how the firing events that occur in the battle are recorded. The logical player number (**LPN**) identifies the platform of the firing weapon. Because several weapons may be operating on the same platform, the weapon that is firing (**WPN**) is also identified. The grid location of the firing system (**WPN X, WPN Y**) and the time (**Time**) of the event are also included in FET.NTC. The file contains no information as to the target or the effect of the engagement.

The weapon number (**WPN**) referred to in Table 3.7, is described in another table (Table 3.9) that contains the weapon number (**WPN**). the number of weapons available (**# AVAIL**), the rate of fire at which the weapon is capable of firing (**ROF**), the operational lethality index associated with the weapon (**OLI**), and a short description of the weapon (**DESCR**).

There is a separate file called IFMF.NTC (Table 3.8) which lists all of the indirect-fire missions that were executed during the battle. In this example, only the howitzer (HOW) is an indirect-fire weapon. IFMF.NTC contains the logical player number (**LPN**), the assigned firing mission number (**MSN**), the firing weapon's grid location (**WPN x** and **WPN y**), the explosive shell type (**Shell**), the grid location of the target (**TGT x** and **TGT y**), and the time of the event (**Time**).

All of the data manipulation subroutines and computational subroutines used to operate on the actual database files are listed and documented in Appendix B.

Table 3.7: Example of FET.NTC (Fire Event Table)

LPN	WPN	WPN x	WPN y	Time
IFV	8	182	305	2
S1	1	162	288	2
S1	1	162	288	4
T1	2	147	297	5
M1	7	164	272	5
M1	7	164	272	5
TOW	6	153	274	5
M1	7	154	292	6
TOW	6	138	292	6
S2	1	145	329	6

Table 3.8: Example of IFMF.NTC (Indirect Fire Table)

LPN	MSN	WPN x	WPN y	Shell	TGT x	TGT y	Time
HOW	1	281	216	HE	160	280	1
HOW	2	281	216	HE	180	281	1
HOW	3	236	240	HE	150	310	5
HOW	4	236	240	HE	150	310	5
HOW	5	236	240	HE	150	310	5

Table 3.9: Weapons Data

WPN	# AVAIL	ROF	OLI	DESCR
1	2	95	103.56	AT3 Sagger
2	2	90	271.00	125mm Tank Gun
3	4	2100	1.32	12.7mm MG
4	3	2200	.57	7.62mm COAX MG
5	2	2100	1.51	12.7mm MG
6	1	95	226.55	TOW missile
7	1	92	255.28	120mm main tank gun
8	1	250	11.31	25mm main gun
9	1	20	10.38	Stinger
10	1	48	227.92	155mm Howitzer

3.8.3 Computing the Measures

Once the data from the battle has been collected and organized into a database, measures can be calculated using the algorithms summarized in the previous section. For this example, the problem was small enough to allow calculations by hand and by spreadsheet.

Agility

Agility has three components, Organizational, Mental, and Physical Agility, which have corresponding measures. They are described in detail in Section 3.5 and 3.6. A description of how each would be calculated for the example problem follows.

Organizational Agility Organizational agility depends upon the staff and the commander of the unit developing alternative courses of action and then publishing and distributing the commander's decision as an order. At H-

60 (60 minutes before the the attack begins) the commander received the mission of attacking the position that the enemy occupies, Grid 1532 (see Figure 3.21). The staff (in this case the small unit leader himself) developed two alternative courses of action within 15 minutes. The commander decided upon one of the courses of action and issued the order to the rest of his unit at H-30 (30 minutes before the planned attack). The time required for organizational tasks was 30 minutes while the total time available prior to the battle was 60 minutes. The raw value for publishing speed related to organizational agility is $\frac{30}{60} = \frac{1}{2}$. Current doctrine stresses getting the orders published within one-third of the remaining time so subordinate units may optimize their preparations. The raw value is transformed to a normalized value using the algorithm discussed in Section 3.5.1 and shown below. Because no times are available for the production of fragmentary orders, the normalization process is based only on the operations order.

$$OA(X) = MIN[1, \frac{3}{2}(1 - X)]$$

In this case,

$$OA(\frac{1}{2}) = MIN[1, \frac{3}{2}(1 - \frac{1}{2})] = MIN[1, \frac{3}{4}] = \frac{3}{4}$$

Mental Agility The commander's mental agility is measured by how fast the decisions during the battle are made. The only decision during the battle that subsequently changed the original plans was the decision to maneuver around to the South and attack the position South to North. This decision was made by the commander after learning of the number of weapon systems directly in front of his unit. The Infantry Fighting Vehicle (IFV) discovered the enemy and eventually was destroyed. At H+30 the information of the

enemy locations reached the commander. At H+35 the commander decided to change the original plan to head directly to the objective. There was only one such decision evident during this battle. The time for the commander to make a decision was 5 minutes. Using the measures from Section 3.5.2. we calculate the Mental Agility Measure.

$$MA_{speed} = 0.2/min$$

$$MA_n = 1$$

The normalization of these raw values cannot be done until more empirical evidence or a published standard is available.

Maneuver The component of physical agility is modeled by the measure called maneuver. Table 3.10 shows how the maneuver measure was calculated using a spreadsheet. The grid coordinates, (x1. y1) — (x6. y6) represent the locations of the different friendly platforms during the six time periods. The euclidean distance between grids of the same asset during adjacent time periods (e.g., (x1,y1) for AD to (x2, y2) for AD) is calculated and displayed in the Dist$(1-2)$ row. The average speed for each platform is calculated using total distance traveled while moving during the battle divided by the total time spent traveling. For example, the IFV only moved once - after the first time period. After moving 3,354 meters in 15 minutes, it never moved the rest of the battle. A speed of $\frac{3354}{15min}$ yields an average speed of 13,416 meters/hour. The maximum speed for each platform is available in the database shown earlier in this example.

The raw value was obtained by dividing the average speed by the maximum speed. All of the normalized values were weighted by their respective

Table 3.10: Sample Maneuver Value Worksheet

LPN	AD	HOW	IFV	TOW	M1
OLI	14	402	746	195	712
x1	22,000	28,100	21,500	22,600	23,200
y1	30,600	21,600	29,900	31,200	28,500
x2	23,400	28,100	18,200	20,700	24,000
y2	32,000	21,600	30,500	31,500	28,600
Dist(1–2)	1,980	0	3,354	1,924	806
x3	19,600	28,100	18,200	18,800	21,800
y3	27,100	21,600	30,500	24,800	25,300
Dist(2–3)	6,201	0	0	6,964	3,966
x4	16,900	23,600	18,200	15,500	16,300
y4	26,100	24,000	30,500	24,700	25,700
Dist(3–4)	2,879	5,100	0	3,302	5,515
x5	15,700	23,600	18,200	15,300	16,400
y5	28,100	24,000	30,500	27,400	27,200
Dist(4–5)	2,332	0	0	2,707	1,503
x6	15,700	23,600	18,200	13,800	15,400
y6	28,100	24,000	30,500	29,200	29,200
Dist(5–6)	0	0	0	2,343	2,236
Avg Speed (m/hr)	13,392	20,400	13,416	13,792	11,221
Max Speed (m/hr)	80,000	56,000	66,000	64,000	67,000
Raw Value	0.167	0.364	0.203	0.215	0.167
OLI Weighted	2.344	146.443	151.646	42.022	119.244
Maneuver Value		**0.223**			

OLI values, summed and then divided by the sum of the OLI values. The final value was 0.223. Theoretically the value could have taken on values from 0.0 to 1.0. A value of 1.0 would indicate that every time any asset changed its location, it traveled at the maximum road speed possible for that platform. Since most of the travel is not on roads, this theoretical maximum is difficult to attain. A value of 0.223 is between the 70th and 80th percentile as established by the values from actual battles fought at the NTC and reported in Chapter 4. This relatively high value reflects good movement of combat power around the battlefield. Intuitively, one can observe the battle snapshots and determine that the friendly forces reacted quickly after locating the enemy and losing their first weapon system.

Synchronization

Combined Arms The concept of using all weapon systems available to provide either a balanced attack or a balanced defense is measured here. As described in Sections 3.6, the combined arms measure depends upon the four normalized BOS values including maneuver, fire support, air defense, and MCMS.

The maneuver BOS value is calculated in Table 3.12 and normalized by dividing the sum by the total OLI possible. Sorted according to weapon type (**WPN**), Table 3.11 contains the number of weapons of that type available to the friendly commander (**# WPN Avail**), the total number of rounds fired by that weapon type (**# RdsFired**), and the theoretical sustained, hourly, rate of fire (**RoF**).

In Table 3.12, the value for the three weapons that are direct-fire weapons are calculated. The total OLI for a weapon (**Tot OLI**) is computed from

Table 3.11: Tabulated Data for Sample Battle Firing Events

WPN	1	2	3	4	5	6	7	8	9	10
# WPNs Avail	2	2	4	3	2	1	1	1	1	1
# Rds Fired	3	1	0	0	0	2	3	1	0	5
RoF	95	90	2100	2200	2100	95	92	250	20	48

Table 3.12: Maneuver Weapons Usage

WPN	# Rds Fired	OLI/Rd	Total OLI
6	2	226.55/95	4.77
7	3	255.28/92	8.32
8	1(50rds)	11.31/250	2.26
Total			15.35
Normalized	Value		**0.032**

multiplying the number of rounds that were fired during the battle (**# Rds Fired**) by the calculated OLI per round (**OLI/Rd**). A value of 0.032 places this battle's maneuver assets' usage between the 50th and 60th percentile. The value will necessarily be low if the direct-fire assets are not within effective firing distance of any enemy assets.

The fire support portion of the combined arms calculations is performed similarly. One howitzer fired 5 missions. Those five missions produced Table 3.13. Based on the results from the actual NTC battles, 0.104 is between the 10th and 20th percentile. The howitzer could have fired much more than it did. Five rounds in 1.25 hours is not considered good use of an artillery weapon.

The air defense portion of the combined arms measure depends upon the location of the friendly assets and the location of the air defense assets. The

Table 3.13: Fire Support Calculations

WPN	# Rds Fired	OLI/Rd	Tot OLI	Normalized Value
Howitzer	5	227.92/48	23.74	**0.104**

assets are considered adequately covered if they are within 1/3 of the effective range of the air defense asset. The locations and ranges of assets in each of the 6 time periods produce the results in Table 3.14.

Table 3.14: Combined Arms ADA

Period	OLI Protected	Total OLI	Value
1	955	2069	0.46
2	0	2069	0.00
3	0	1323	0.00
4	726	1323	0.55
5	921	1323	0.70
6	0	1309	0.00
ADA Value			**0.285**

The ADA value of 0.285 places this battle between the 30th and 35th percentile. The Stinger (ADA missile) could have been located more centrally to better cover more of the force's assets.

The MCMS (Off) value could not be calculated for this battle. No minefields were laid, no bridges had to be built or destroyed, and no positions were dug. There was no obstacle to build or breach.

The final combined arms value is the variation of the four battlefield operating system values (see Table 3.15). For the sample battle, the variation, which is computed exactly like a population variance, is 0.0172. The range of each of the normalized values is $[0, 1]$. Without the MCMS value. the range of the variation of three normalized values is: $0.0 \leq CA \leq 0.22$. The

Table 3.15: Combined Arms

BOS	Max OLI	Actual OLI	BOS Value
Maneuver	508.25	15.35	0.030
Fire Spt	227.92	23.74	0.104
ADA	14.00	4.00	0.285
	Max Var	Act Var	Overall
C A Value	0.22	0.0172	**0.9218**

normalized Combined Arms value is:

$$CA = \frac{0.22 - 0.0172}{0.22} = \mathbf{0.9218}$$

This value indicates that the combined arms effort of the battle is between the 50th and 60th percentile.

Weapons Usage The same calculations of battlefield operating systems are needed for the weapons usage value. The component being measured is the amount of overall weapon usage. should be helpful in explaining the Weapons Usage value. The columns of Table 3.16 are Battlefield Operating System (**BOS**), the maximum possible OLI (**Max OLI**), the computed OLI (**Actual OLI**), and the normalized value for that BOS, (**BOS Value**). The normalized value is the percent of the maximum possible OLI that the actual OLI represents.

The Weapons Usage value was calculated in exactly the same manner as the method used for calculating the normalized values for the battlefield operating systems. A value of 0.075 places the battle's weapon usage between the 40th and 50th percentile. Several of the friendly systems had no enemy assets within range for several of the time periods which necessarily reduces

Table 3.16: Weapons Usage

BOS	Max OLI	Actual OLI	BOS Value
Maneuver	508.25	15.35	0.030
Fire Spt	227.92	23.74	0.104
ADA	14.00	4.00	0.285
W U Value	750.17	43.09	**0.075**

the level of weapon use.

Control The control measure is divided into spatial and temporal control. The calculations for these two measures were performed in a spreadsheet and are shown in the tables below.

Table 3.17 through Table 3.22 show the results of visual inspection of each of the battle configurations to find the combat power densities associated with each grid square. The grid sizes were chosen to be 2000m $\times$ 2000m. In each grid square, if a range circle reaches the center of the grid square, that grid is assumed to have one square's worth of combat power (OLI) density from the respective asset. The densities are additive if the assets belong to the same side. Therefore, in each of the six pages of tables, there are two density matrices (friendly and enemy), and two asset matrices (enemy and friendly, respectively).

The spatial control value for each time period is calculated by using the entropy calculation described previously in Section 3.6. The p in the equation is the proportion of the total combat power that is contained in each cell. Table 3.23 shows the results of the calculations after summing the entropy values for each cell over the entire matrix. The sum of the entropy

Table 3.17: Density and OLI Matrices for Period 1

Friendly Density									
0.00	0.00	0.00	0.00	0.00	0.00	17.66	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	22.04	22.04	20.06	2.40	0.00
0.00	0.00	0.00	0.00	22.04	248.02	248.02	94.06	2.40	0.00
0.00	0.00	0.00	2.40	2.40	248.02	248.02	94.06	2.40	0.00
0.00	0.00	0.00	2.40	2.40	76.41	76.41	76.41	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	76.41	2.40	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	2.40	2.40	2.40	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enemy Assets									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enemy Density									
0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	506.96	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	701.98	29.14	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	195.02	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Friendly Assets									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	14.00	195.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	746.00	712.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	402.00

Table 3.18: Density and OLI Matrices for Period 2

				Friendly Density					
0.00	0.00	0.00	0.00	17.66	17.66	1.98	0.00	0.00	0.00
0.00	0.00	0.00	0.00	17.66	22.04	22.04	4.38	2.40	0.00
0.00	0.00	0.00	169.63	172.03	96.04	96.04	78.39	2.40	0.00
0.00	0.00	0.00	154.38	172.03	94.06	94.06	76.41	2.40	0.00
0.00	0.00	0.00	2.40	2.40	76.41	76.41	76.41	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	76.41	2.40	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	2.40	2.40	2.40	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Density					
0.00	0.00	0.00	0.00	17.66	17.66	1.98	0.00	0.00	0.00
0.00	0.00	0.00	0.00	17.66	22.04	22.04	4.38	2.40	0.00
0.00	0.00	0.00	169.63	172.03	96.04	96.04	78.39	2.40	0.00
0.00	0.00	0.00	154.38	172.03	94.06	94.06	76.41	2.40	0.00
0.00	0.00	0.00	2.40	2.40	76.41	76.41	76.41	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	76.41	2.40	2.40	0.00
0.00	0.00	2.40	2.40	2.40	2.40	2.40	2.40	2.40	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Friendly Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.19: Density and OLI Matrices for Period 3

				Friendly Density					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	2.40	2.40	2.40	2.40	0.00
0.00	0.00	0.00	0.00	2.40	2.40	2.40	2.40	2.40	0.00
0.00	0.00	0.00	2.40	4.38	78.39	76.41	2.40	2.40	0.00
0.00	0.00	0.00	22.04	96.04	96.04	76.41	2.40	2.40	0.00
0.00	0.00	20.06	20.06	96.04	96.04	76.41	2.40	2.40	0.00
0.00	0.00	2.40	20.06	94.06	94.06	76.41	2.40	2.40	0.00
0.00	0.00	0.00	0.00	17.66	0.00	0.00	0.00	0.00	0.00
				Enemy Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Density					
0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	506.96	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	701.98	29.14	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	195.02	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Friendly Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	746.00	195.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	712.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	402.00

Table 3.20: Density and OLI Matrices for Period 4

				Friendly Density					
0.00	0.00	0.00	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	0.00	2.40	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	2.40	2.40	2.40	2.40	2.40	2.40	0.00	0.00	0.00
2.40	2.40	76.41	78.39	2.40	2.40	2.40	0.00	0.00	0.00
2.40	94.06	96.04	96.04	78.39	2.40	2.40	0.00	0.00	0.00
2.40	94.06	96.04	96.04	96.04	2.40	2.40	0.00	0.00	0.00
0.00	17.66	94.06	17.66	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	17.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Density					
0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	506.96	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	701.98	29.14	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	195.02	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Friendly Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	195.00	712.00	0.00	0.00	402.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.21: Density and OLI Matrices for Period 5

Friendly Density									
0.00	0.00	0.00	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	0.00	2.40	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	2.40	4.38	2.40	2.40	2.40	2.40	0.00	0.00	0.00
2.40	2.40	96.04	96.04	76.41	2.40	2.40	0.00	0.00	0.00
2.40	94.06	96.04	96.04	76.41	2.40	2.40	0.00	0.00	0.00
2.40	20.06	94.06	94.06	76.41	2.40	2.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enemy Assets									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	311.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	180.45	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enemy Density									
0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	506.96	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	701.98	29.14	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	195.02	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Friendly Assets									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	195.00	712.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	402.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3.22: Density and OLI Matrices for Period 6

				Friendly Density					
0.00	0.00	0.00	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	17.66	20.06	2.40	2.40	2.40	2.40	0.00	0.00	0.00
17.66	94.06	94.06	94.06	2.40	2.40	2.40	0.00	0.00	0.00
20.06	94.06	94.06	94.06	76.41	2.40	2.40	0.00	0.00	0.00
20.06	94.06	94.06	76.41	76.41	2.40	2.40	0.00	0.00	0.00
2.40	2.40	2.40	2.40	2.40	2.40	2.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	506.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Enemy Density					
0.00	14.57	14.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.02	506.96	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	14.57	195.02	14.57	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Friendly Assets					
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	195.00	712.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	402.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

values is then compared to the theoretical minimum and theoretical maximum entropies to normalize the measure. Finally, the values are averaged to obtain the spatial control value for the battle. At 0.0778, the spatial control is below the 10th percentile. The low value seems to be caused by the howitzer having such a large range and comparatively large OLI in this battle. Usually there are many more M1 tanks and Infantry Fighting Vehicles (IFV) than howitzers. The howitzer's range affects the value because there is no way to concentrate its combat power into a few grid squares, and there is no method for overlapping effective ranges with other artillery weapons. As the area included in the battle increases and the number of maneuver assets dramatically increases, the howitzers have less of an entropy increasing effect and there is more potential for concentrating combat power.

Table 3.23: Spatial Control Calculations for Sample Problem

Spatial Control Calculations					
Time Period	Friendly OLI	Sum of Entropy	Min Entropy	Max Entropy	Spatial Control
1	2069	0.9472	0.7782	1.6924	0.8151
2	2069	1.0853	0.7782	1.6924	0.6641
3	2069	0.8027	0.7782	1.6924	0.9731
4	1323	1.0797	0.7782	1.8131	0.7086
5	1323	0.9454	0.7782	1.8131	0.8384
6	1309	1.1177	0.7782	1.7976	0.6669
Final Spatial Control Value					**0.7777**

The temporal control value is computed differently. Instead of each time period's spreadsheet of densities being the basis for the entropy calculations, each grid square over time becomes the basis. Each grid square has six entropy calculations that must be summed. The results of the summations are

Table 3.24: Temporal Control Table for Sample Problem

Temporal Control Calculations									
Grid by Grid Entropy Results									
0	0	0	0.4771	0.3997	0.3997	0.4846	0	0	0
0	0	0.2713	0.4771	0.3997	0.5589	0.5589	0.3168	0.4771	0
0	0.0990	0.1260	0.3222	0.2574	0.3207	0.3207	0.3266	0.4771	0
0.2713	0.0990	0.4749	0.6104	0.4970	0.4548	0.4535	0.3263	0.4771	0
0.2713	0.4771	0.4771	0.5873	0.6284	0.5302	0.5363	0.3310	0.4771	0
0.4771	0.2413	0.4745	0.4745	0.5274	0.2292	0.5363	0.4771	0.4771	0
0	0	0.1454	0.4534	0.0990	0.0990	0.1153	0.4771	0.4771	0
0	0	0	0	0	0	0	0	0	0
Min Entropy		Actual Entropy		Max Entropy		Temporal Control Value			
0.00		0.4177		0.7782		**0.4633**			

found in the matrix in Table 3.24. Each cell's entropy sum is weighted by the proportion of combat power found in the cell over the duration of the battle. The weighted average of the cell values gives the temporal control value of 0.4177. The normalized TC value of 0.463 is well above the 90th percentile. The assets continued to move (thus change grid densities) throughout the battle. The entire force moved without leaving a reserve. Reserves and other assets that change their positions very little over the course of a battle cause temporal control values to be relatively low. In this case, the friendly force reacted quickly and completely to changing conditions in the battle. For both the temporal and spatial control measures, the artificially small number of players biased the results to show greater control than was actually the case. (The same behavior with more assets would have given results near the 50th percentile.)

Doctrinal Positioning The two measures identified with doctrinal positioning are combat power projection and invulnerability. Both measures deal with overlap in space and time of one force's area of effectiveness and the other force's location of assets. The example is simple enough to allow visual as well as computational awareness of the overlap.

Combat Power Projection The combat power projection measure (CPP) indicates the level of overlap, time period by time period, of the friendly force's area of effectiveness and the opposing force's assets' locations. The same matrix used for calculating spatial control provides the friendly density information needed to match against the opposing force's asset matrix. In Table 3.17 to Table 3.22, each cell of the enemy asset matrix is multiplied with its corresponding cell from the friendly density matrix. In period one, such multiplication yields zeros for every cell except one. In cell (4,4), which corresponds to grid square 1628 in the original battle configurations, contains 2.40 in friendly OLI density from the Howitzer, and 14.57 in opposing force asset value from the AT3 Sagger (S1). The total of the cell products appears in the CPP & IV table (Table 3.25) in the 6th column (**CPP Overlap**). In Period One the value was only 34.99. Each time period has its own CPP value. Dividing the actual CPP value by the maximum CPP value produces a normalized CPP value. The maximum value possible is simply the product of the maximum density (**Max Den**) and the total enemy assets' OLI. The final CPP value is the average of the six individual CPP values.

The CPP value of 0.103 places the example battle's power projection between the 90th and the 100th percentile. As seen in the configurations

and then verified by the individual CPP values, the first three time periods saw very little offensive overlap. The second three time periods were well above the final average value and coincided with the time periods in which the attack occurred. As platforms were destroyed, each remaining asset increased in relative importance. The CPP value is also sensitive to the normalization method which had to be slightly modified for the example.

Table 3.25: CPP & IV Calculations for Sample Problem

Combat Power Projection and Invulnerability Calculations								
Time Period	Friendly MaxDen	Enemy MaxDen	Friendly OLI	Enemy OLI	CPP Overlap	IV Overlap	CPP Value	IV Level
1	248.02	701.98	2069	1,014	35	0.00	0.00014	0.00
2	172.03	701.98	2069	1,014	2,249	0.00	0.01290	0.00
3	96.04	701.98	2069	1,014	35	0.00	0.00036	0.00
4	96.04	701.98	1323	1,014	16,896	204.00	0.17350	0.00002
5	96.04	701.98	1323	1,014	21,314	15,946	0.21888	0.00107
6	94.06	506.96	1309	507	10,168	0.00	0.21323	0.00
Avg							0.10317	0.00054

Invulnerability Invulnerability calculations are similar to CPP calculations. Calculation of invulnerability utilizes the opposing force's density matrix and the friendly force's asset OLI matrix. As shown in the 7th column (**IV Overlap**) of Table 3.25, the first three time periods found no overlap between the assets and the densities. The fourth time period had a small amount of overlap and the fifth time period had a very large overlap. In the fourth period, only one friendly asset (AD) was within the range of an opposing force asset (S1). All other cells (grids) had either zero density, zero assets, or both. Refer to Table 3.17 to Table 3.22. During the fifth time period the opposing density area of the AT3 Sagger (S1) overlapped with the air defense platform (AD), the Abrahms tank (M1), and the anti-tank

missile (TOW). The opposing force tank (T1) density circle also overlapped with the air defense (AD) platform. The final value of 0.999458 is between the 90th percentile and the 100th percentile for invulnerability values. The commander and the crew members were clearly aware of the range differences and used them to their advantage. The friendly force did not decide to follow the IFV platform into the opposing force's kill zone, reference Table 3.24. Had they entered the kill zone with other assets, the *vulnerability* would have been much higher and the invulnerability *value* would have been forced lower.

Summary of the Numerical Results

Table 3.26: Measure Values for Example Battle

Measure	Value
Organizational Agility	0.750
Mental Agility	5 min
Maneuver	0.223
Combined Arms	0.922
Weapons Usage	0.075
Spatial Control	0.778
Temporal Control	0.463
Cbt Pwr Projection	0.103
Invulnerability	0.999458

Table 3.26 shows a list of the values calculated for the measures of the sample battle. This section of Chapter Three is included to give the reader a better idea of exactly how the measures are calculated for a battle that has the required data available. This is not a typical battle and has been artificially simplified to allow for more simple calculations. The reader who is unfamiliar

with combat models or war games should now have a good idea of the type and quantity of data available from instrumented training battles.

CHAPTER 4

Experiment

4.1 Purpose

The purpose of this experiment is to test the relationship between proposed measures of subcomponents of doctrine and the subjective evaluations of the subcomponents by experienced U.S Army officers. The test vehicle will be training battles fought at the NTC. Given the numerical data from a completed training battle, the value of a measure can be computed. But the results of a battle exercise include not only numerical data but also narrative material, videotapes, and opinions and critiques; from these materials an expert can make subjective evaluations of the same conformances to subcomponents of doctrine that the computed values of the proposed measures purport to indicate.

There is currently no well-established or well-accepted objective measure for any of the subcomponents analyzed in Chapter Three. If an objective measure were available, the experiment would be quite straightforward. Even subjectively, many of the concepts are not commonly evaluated and very few military experts are accustomed to being required to evaluate commanders and units using these measures. Therefore, a more indirect approach must be

taken. The experiment will not attempt to prove the significance and *consistency* of the relationship between the components and the objective measures. The experiment will be conducted to test if experienced officers evaluate a battle as showing high conformance to doctrine when the objective measure is high. Similarly, it will be conducted to test whether experienced officers evaluate a battle as showing low conformance to doctrine when the objective measure is low. Because the officers have not been trained in numerically evaluating these areas, only gross evaluations will be possible. The set of battles to be evaluated will be limited to those for which very high or very low values of the measures were produced. The results of these tests will be evaluated using a non-parametric statistical test, since no known probability distribution can be assumed. The results will test the claim that when an objective measure is high, the experts will evaluate the battle as having high conformance to doctrine and when the objective measure is low, the experts will evaluate the battle as having low conformance to doctrine.

4.2 Choosing the Battles

Each battle will be evaluated *objectively* by calculating the values for the measures and *subjectively* by surveying the experts after they have viewed the electronic replay and have read a summary of the battle. We must choose specific battles to be representative of the major factors that affect the outcome of a battle, and we must control for the effects of factors that are not measured. One of the purposes of NTC is to allow soldiers to experience the equivalent of actual battle. NTC was chosen over other training areas for this experiment because of its realism and its degree of instrumentation,

allowing more data to be gathered, stored, and made available.

4.2.1 Battle Classification Variables

As portrayed in the diagram in Figure 1.1, many variables, either directly or indirectly, affect the outcome of battle. These variables must either be controlled for, blocked, or classified as insignificant in their effects upon the measured results of the battles examined in this research. The paragraphs below contain the discussions of the possible variables that could have an effect upon the results.

Type of Unit

Discussion The unit may be Armor (predominantly tanks), Infantry (many foot soldiers), Mechanized (some tanks and soldiers mounted on armored vehicles) or a mixture of these three types.

Control Since a few battles could be used in the experiment, the unit type was limited to Mechanized Infantry. This type of unit has many different weapons and yields a richer data set than either an Armor unit or as an Infantry unit.

Terrain

Discussion Operations are often altered based upon terrain. Mountainous terrain favors dismounted Infantry whereas flat, desert-like terrain favors the tank and other long range, highly mobile armored vehicles. Rolling hills with trees and other vegetation favors Mechanized Infantry.

Control The terrain at Fort Irwin, California is quite rugged. Although different battles began in mountainous, or flat, or washboard terrain, these three types of terrain were all encountered sometime during each of the battles. Data were not available to associate terrain type with events. and nearly all measures were based on many events and were associated with a mixture of terrain types. Terrain was not usable as a major factor in the outcome in the 21 chosen battles.

Weather

Discussion Rain, fog, snow, heat, or high winds all adversely affect combat operations. Visibility, morale, communications, movement, and endurance all are affected by weather and are factors themselves in battle.

Control Weather conditions were not recorded for any of the battles and could not be used to discriminate between battles' results.

Enemy

Discussion The number, tactics, and type of enemy unit faced can affect the value of friendly actions in battle. Thus, knowledge of these can affect the course of action decision.

Control Although there is a certain degree of flexibility for the opposing forces, the size and composition of the OPFOR for a given mission is controlled. The OPFOR must act consistently with Soviet-style doctrine (for this scenario). We considered this control to be adequate and did not discriminate between battles on the basis of size or composition or tactics of the opposing force.

Resources Available

Discussion The number, type, and availability of equipment, soldiers, ammunition, food, fuel, and even spare parts could all play critical roles in the outcome of a battle.

Control Throughout the course of the battle, each of the measurables that deal with the level of resources (ammunition, number of vehicles, combat power) is normalized by the level available. Other than the normalization that occurs within the measures' algorithms, no other control or experimental design based on resources was included.

Mission

Discussion The type and scope of a mission is critical to the probability of success of the unit. A unit may be well suited for a short-lived

defensive operation against an opposing infantry unit but may be ill suited for a prolonged defensive stand against an armored force.

Control The missions were varied and continued to be varied throughout every set of battles at the NTC. The two most important and distinguishable classes of missions, offense and defense, are in the database and available for selection. The experiment included 14 offensive and 7 defensive missions.

Level of Training

Discussion The training level of the soldiers and leaders affects tactical and technical proficiency and decision-making skill.

Control The level of training of both the opposing force's soldiers and the participating friendly unit's soldiers was not judged to be significantly different between battles or between forces. Perhaps results of standard tests such as the skill qualification test (SQT) or the most recent ARTEP would be positively correlated with doctrinal conformance. Scores of training evaluations were not available. Work is currently being done by the Army Research Institute to develop such a measure [Holz 94]. Dupuy also developed and proposed a strategy for measuring the level of training of a unit [Dupuy 85]. It may be possible to include level of training in future research efforts.

Morale

Discussion Morale can definitely affect which decisions are made and how the orders are carried out.

Control Although undeniably an important factor, morale was not recorded or evaluated consistently. Thus, it became part of the intangible, immeasurable factors of battle which can increase or decrease a unit's efficiency. The videotaped After-Action Reviews failed to consistently mention the level of morale.

Day/Night Operations

Discussion Movement is usually slower at night. Units travel closer together. Effective ranges of weapons are decreased. Certain advantages may occur at night due to advanced technology that are not present during daylight hours.

Control Some battles had a covering force operation out in front of the main battle area prior to daylight hours and some initiated the main battle within an hour of daylight, but the majority of every battle reviewed took place during daylight. Light was not used as a variable in the experiment.

Time Available

Discussion The difficulty of a mission can increase significantly as the amount of preparation time is reduced.

Control Time available was controlled by the staff of NTC for each tactical mission. Similar missions during different rotations received approximately the same preparation and warning time. The use of time for preparation and planning is a critical part of Organizational Agility and is explicitly measured for each battle. There was no attempt to select different battles based on time to prepare.

Type of Training

Discussion All of the battles in this experiment are taken from the National Training Center (NTC). There are two major types of training: Force-on-Force and Live-Fire training. Both types have been addressed in detail in Chapter One.

Control Because there was no actual enemy force with working vehicles and weapons in the Live-Fire training, both of which are critical in several of the measures, the battles for the experiment were restricted to Force-on-Force.

Data Storage

Discussion Although many battles were available for viewing and evaluating, a large number of them did not have digital databases (Range Differential Measurement System (RDMS)) that could be queried for the critical data requirements addressed in Chapter Three.

Control We selected only battles for which the NTC used RDMS.

Using the factors just mentioned, we selected the first 21 NTC battles that had the following characteristics:

- Mechanized Infantry Battalion-level Task Force
- A battle that used RDMS
- A battle from the Force-on-Force training area
- An adequate number of offensive and defensive missions to yield a representative range of behavior. Five or six battles of each mission type would be adequate.

The 21 battles selected spanned two years of training at the NTC. They should yield a representative sample of the levels of conformance to doctrine in each of the specified areas. Of the 21 battles, 14 were offensive missions and 7 were defensive missions.

4.3 Objective Battle Scores

Many of the measures are computationally intensive. The FORTRAN code required to accomplish these calculations is in Appendix B. The list below

shows all of the measures that were calculated. Those preceded by ** are the measures simple enough to have their calculations shown in this section.

- **Organizational Agility
- Maneuver
- **Combined Arms as a function of:
  - Use of Maneuver Assets
  - Use of Fire Support Assets
  - Use of ADA Assets
  - **Use of MCMS Assets
- Spatial Control
- Temporal Control
- **Weapons Usage as a function of:
  - Use of Maneuver Assets
  - Use of Fire Support Assets
  - Use of ADA Assets
  - **Use of MCMS Assets
- Combat Power Projection
- Invulnerability

Although 21 NTC battles were reviewed and chosen for measurement, eight of the data files were irretrievable. Twelve measures were calculated for each of the remaining 13 battles. Table 4.1 shows these calculated values. From left to right, this table contains the mission number, Maneuver value, Armor/Infantry Firepower value, Fire Support value, Air Defense value, Engineer's value, Combined Arms value, Spatial and Temporal Control values, Overall Weapon Usage value, Combat Power Projection value, and Invulnerability value.

The last four rows of Table 4.1 give the computed minimum, maximum, mean, and standard deviation for each of the 12 measures.

Table 4.2 shows how the values in the second column in Table 4.1 were calculated. For example, during the battle in MSN 2, the battalion task force staff and commander took about one-half of the total preparation time given them by the brigade to issue the order to the battalion's subordinate units. Using the formula

$$OA_s(\frac{1}{2}) = MIN[1, \frac{3}{2}(1 - \frac{1}{2})] = MIN[1, \frac{3}{4}] = \frac{3}{4}$$

we arrive at the value in the third column of row two: 0.75. The data used for the Organizational Agility computations was available in the form of percent-of-time-used. It is contained in the summary of the battle (see Appendix A).

Table 4.3 is a worksheet that shows how the final values for the Mobility, Counter-Mobility, and Survivability (MCMS) were calculated. In MSN 5, there were two types of Engineer equipment available, ACE and SEE. Row three shows that with the number of ACEs available, 78 positions could have been dug. Row two (ACE NTS Positions) shows that 25 positions were dug

Table 4.1: Objective Measure Values and Statistics

MSN #	Org Agility	Maneuver	Combined Arms	Spatial Control	Temporal Control	Weapon Use	Cbt Pwr Projection	Vulner-ability
01	1.0	0.0820	0.7408	0.5706	0.0858	0.0495	0.0324	0.9783
02	0.75	0.1170	0.3679	0.5144	0.0234	0.1729	0.0516	0.9962
03	0.5	0.2300	0.9369	0.4981	0.0945	0.0173	0.0706	0.9714
04	0.75	0.0580	0.8036	0.5193	0.0115	0.0786	0.0344	0.9944
05	1.0	0.1110	0.6888	0.4924	0.0116	0.2786	0.0035	0.9997
06	1.0	0.1200	0.8526	0.7801	0.0791	0.0455	0.0314	0.9901
10	0.833	0.3370	0.9930	0.6753	0.0802	0.0348	0.0208	0.9778
11	0.75	0.1400	0.8543	0.5223	0.0458	0.1294	0.0450	0.9788
12	0.75	0.0410	0.8873	0.6039	0.0038	0.2316	0.0054	0.9882
13	1.0	0.2850	0.9791	0.6242	0.0115	0.0612	0.0613	0.9581
17	1.0	0.0790	0.9509	0.8047	0.0545	0.0910	0.0052	0.9990
18	0.75	0.1240	0.7361	0.6143	0.0207	0.4002	0.0328	0.9930
20	1.0	0.0900	0.5213	0.8744	0.0899	0.1772	0.0059	0.9986
Min	0.50	0.0410	0.3679	0.4924	0.0038	0.0173	0.0035	0.9581
Max	1.0	0.3370	0.9930	0.8744	0.0945	0.4002	0.0706	0.9997
Mean	0.852	0.1395	0.7933	0.6226	0.0471	0.1360	0.0308	0.9864
StDev	0.160	0.0895	0.1771	0.1265	0.0350	0.1130	0.0222	0.0127

Table 4.2: Organizational Agility Calculations

MSN #	Fraction of Time Used to Issue Order	Agility Measure Value
1	1/4	1.0
2	1/2	0.75
3	2/3	0.5
4	1/2	0.75
5	1/6	1.0
6	1/3	1.0
10	4/9	0.833
11	1/2	0.75
12	1/2	0.75
13	1/3	1.0
17	2/9	1.0
18	1/2	0.75
20	1/3	1.0

Table 4.3: Worksheet for Defensive Engineer Values

	MSN 2	MSN 5	MSN 7	MSN 11	MSN 18	MSN 19	MSN 20
ACE OK	6	33	14	30	20	4	
ACE NTS Positions	5	25	41	27	28	15	
ACE Poss Positions	50	64	78	82	33	38	
SEE OK	5	12	6	0	9	0	
SEE NTS	6	8	34	4	5	0	
SEE Poss Positions	50	81	62	62	63	24	
Position Value	0.165	0.4241	0.4107	0.3160	0.4740	0.1855	0.3
ACE Hours	33	108	101	88	92	112	
ACE Poss Hours	150	162	155	124	84	114	
SEE Hours	12	20	20	4	30	2	
SEE Poss Hours	50	82	62	62	63	24	
Hour Value	0.225	0.5246	0.5576	0.4946	0.8299	0.8261	0.4
Mines Used	0	2614	0	895	4298	2533	0
Mines Poss Used	0	3414	0	4885	4818	4800	0
Mine Value	0	0.7657	0	0.1832	0.8921	0.5277	0
CA Value	0.189	0.5808	0.4695	0.2986	0.7124	0.4505	0.34
OLI Used	0	7842	0	2685	12894	7599	0
OLI Possible	0	10242	0	14655	14454	14400	0
WU Value	0	0.7657	0	0.1832	0.8921	0.5277	0

that did not meet the standards set by the unit. Row one shows the number of positions dug by the ACEs that were done to standard: 33. Similarly, there were a possible 81 positions that could have been dug by the available SEEs. However, Row 5 shows that 8 positions were dug that did not meet the standards, and Row 4 shows that only 12 positions were dug that met the standards. Using the algorithm described in Section 3.7, the intermediate value of 0.4241 was calculated. The next calculations are similar except that they depend upon the number of hours the equipment (ACEs on Row 8 and SEEs on Row 10) were used compared to the number of hours they could have been used (ACEs on Row 9 and SEEs on Row 11). For MSN 5 we see that the value for engineering equipment usage of available hours is 0.5246. There were 2614 mines used and 3414 mines that could have been emplaced. The ratio of these two values is the Mine Value: 0.7657. In Appendix B a mine has on OLI value of 3.0. Using this OLI value, the total OLI Used should be $3.0 * 2614 = 7842$. The total possible OLI is calculated similarly – $3.0 * 3414 = 10242$.

Table 4.4 shows all of the values and computations involved in calculating the values for the Combined Arms Balance and Weapons Usage measures. The full row names are:

Maneuver Measure Value

Percentile Maneuver Measure Value

Maneuver BOS OLI Used

Maximum Possible Maneuver OLI

Fire Support Measure Value

Percentile Fire Support Measure Value

Table 4.4: Calculations for Combined Arms and Weapons Usage Values

	MSN 1	MSN 2	MSN 3	MSN 4	MSN 5	MSN 6	MSN 10
Man Value	0.0120	0.0163	0.0165	0.0359	0.0883	0.0292	0.0131
Perc Value	0	0.166	0.25	0.583	0.833	0.416	0.083
Man OLI	461	599	423	1057	2885	864	389
Man Max	38310	36740	25680	29420	32670	29570	29680
FS Value	0.1551	0.6374	0.0041	0.1744	0.4042	0.0884	0.1061
Perc Value	0.333	1.0	0	0.416	0.833	0.083	0.166
FS OLI	1875	7693	38	1672	3875	728	867
FS Max	12090	12070	9254	9586	9586	8238	8172
AD Value	0.511	0.5151	0.3564	0.7005	0.3283	0.4832	0.2893
Perc Value	0.583	0.666	0.25	0.916	0.166	0.5	0.083
AD OLI	173.23	223.24	148.73	381.42	163.89	139.89	71.25
AD Max	339	433.4	417.3	544.5	499.2	289.5	246.3
MCMS Value	N/A	0.189	N/A	N/A	0.581	N/A	N/A
Perc Value	N/A	0	N/A	N/A	0.75	N/A	N/A
MCMS OLI	N/A	N/A	N/A	N/A	7842	N/A	N/A
MMS Max	N/A	N/A	N/A	N/A	10242	N/A	N/A
VAR Perc	0.0570	0.1580	0.0139	0.0432	0.0778	0.0324	0.0015
CA Value	0.7408	0.3679	0.9369	0.8036	0.6888	0.8526	0.9930
WU Value	0.0495	0.1729	0.0173	0.0786	0.2786	0.0455	0.0348

	MSN 11	MSN 12	MSN 13	MSN 17	MSN 18	MSN 20
Man Value	0.0751	0.1764	0.0281	0.0298	0.124	0.0826
Perc Value	0.666	1.0	0.333	0.5	0.916	0.75
Man OLI	2607	4047	847	963	3052	2235
Man Max	34720	22940	30150	32330	24610	27060
FS Value	0.2295	0.359	0.1372	0.2574	0.3723	0.4373
Perc Value	0.5	0.666	0.25	0.583	0.75	0.916
FS OLI	1959	2984	1556	2656	3969	4239
FS Max	8535	8312	11340	10320	10660	9694
AD Value	0.619	0.8005	0.4117	0.619	0.3721	0.274
Perc Value	0.75	1.0	0.416	0.75	0.333	0
AD OLI	307.83	292.82	159.29	307.83	170.87	114.07
AD Max	497.3	365.8	386.9	497.3	459.2	416.3
MCMS Value	0.299	N/A	N/A	N/A	0.712	0.340
Perc Value	0.25	N/A	N/A	N/A	1.0	0.5
MCMS OLI	2685	N/A	N/A	N/A	12894	N/A
MCMS Max	14655	N/A	N/A	N/A	14454	N/A
VAR Perc	0.0364	0.0248	0.0046	0.0108	0.0660	0.1197
CA Value	0.8543	0.8873	0.9791	0.9509	0.7361	0.5213
WU Value	0.1294	0.2316	0.0612	0.0910	0.4002	0.1772

Fire Support BOS OLI Used

Maximum Possible Fire Support OLI

Air Defense Measure Value

Percentile Air Defense Measure Value

Air Defense BOS OLI Used

Maximum Possible Air Defense OLI

MCMS Measure Value

Percentile MCMS Measure Value

MCMS BOS OLI Used

Maximum Possible MCMS OLI

Variance of the Percentile Values

Combined Arms Value using the Variance of the Percentiles

Weapons Usage Measure Value

It should be noted that the Combined Arms Balance measure calculates values based upon the magnitude of the variance of the intermediate values. The variance must be of the percentile measure values and not of the actual measures' values since it is clear from Table 4.1 that the measures have significantly different standard deviations and means. The percentile values all come from identical populations.

4.3.1 Interpretation of the Objective Results

Table 4.1 contains 12 calculated measure values for each of the 13 battles that were analyzed. The following paragraphs interpret the values in terms of their doctrinal significance.

Organizational agility is reflected by a unit's speed in publishing Opera-

tions Orders and FRAGOs. This measure's values in Table 4.1 reflect only the unit's speed in publishing Operations Orders. No data were available for the FRAGO computations. Six of the units' staffs were able to publish the order within $\frac{1}{3}$ of the available time and received a perfect value 1.0. Publishing sooner than $\frac{1}{3}$ of the available time does not produce a higher value because it is believed that the staff needs that time to adequately prepare a quality plan. The staff for MSN #3 received a relatively low value of 0.5. Referring to Table 4.2, this staff took $\frac{2}{3}$ of the available time leaving only $\frac{1}{3}$ the time for preparation for battle by the subordinate units. To receive the lowest possible value for organizational agility, a staff would have to take all of the available time to publish the order which would cause the subordinate units to go into battle with no time to prepare. Such a delay in publishing would be reflected by a value of $MIN[1, \frac{3}{2}(1-1)] = 0.0$.

The values for the maneuver measure ranged from 0.0410 to 0.3370. The value for MSN #10 can be interpreted as the unit having moved its combat power about 34% as quickly as it would physically be possible move it, after normalizing for the combat power available and the top speed of the available systems. Recall that this measure does not measure how much a unit moves but how quickly it moves its combat power when it *does* move. To attain the highest possible value of 1.0, every vehicle would have to travel at maximum possible speed whenever it moved throughout the battle. The lowest possible value of 0.0 could be achieved if every vehicle in the unit would travel at zero speed whenever a move was made. Since zero speed produces no change in location, a value of 0.0 is a limit but not physically attainable.

The BOS measures are useful diagnostics in their own right, but also as subcomponent measures for both weapons usage and combined arms.

The maneuver BOS measure received values ranging from 0.0120 to 0.1764 (see Table 4.4, row **Man Value**). A maximum possible maneuver BOS value of 1.0 can be achieved by firing all of the direct-fire weapons (e.g., tank main guns, machine guns, antitank guns, rifles) at the maximum sustained rate for the entire duration of the battle. The minimum value can easily be achieved by not firing any direct-fire weapons at any time during the battle. The unit in MSN #12 fired over 17% of its maximum sustained fire. The unit in MSN #1 was able to fire slightly more than one percent of its maximum sustained fire.

The Fire Support BOS measure had values ranging from 0.0041 to 0.6374 (see Table 4.4, row **FS Value**). Normalizing by the weapons that are available in the unit, the maximum value of 1.0 can be achieved by firing all field artillery, mortars, air support (if available), and naval guns at the maximum sustained rate for the duration of the battle. Close air support and naval guns were not calculated for the battles examined. From Table 4.4. we see that the unit for MSN #3 used almost no fire support, less than one-half of one percent of the maximum sustained fire. The unit for MSN #2 fired over 63% of the maximum sustained fire.

The Air Defense BOS measure had values ranging from 0.274 to 0.8005 (see Table 4.4, row **AD Value**). A maximum value of 1.0 can be achieved by keeping the entire friendly force (with respect to combat power) adequately protected throughout the battle. A friendly asset is adequately protected if it is within $\frac{1}{3}$ of the effective range of at least one Air Defense asset. A minimum value of 0.0 is achieved when the entire friendly force is outside of $\frac{1}{3}$ of the effective range of any Air Defense asset throughout the battle. In MSN #12 an average of over 80in MSN #20 an average of only 20% of the

friendly force was adequately protected from enemy aircraft.

The MCMS BOS measure had values only for the defensive battle. The required MCMS data for offensive battles is not yet recorded during NTC battles. The values ranged from 0.189 to 0.712 (see Table 4.4, row **MCMS Value**). To achieve a maximum value of 1.0, the MCMS assets would have to accomplish the following:

- Use all of the position-digging equipment (SEE and ACE) for the maximum number hours they are available
- Dig the maximum number of positions possible (dictated by the number of hours available and the type of equipment) and ensure each position meets the minimum standards
- Emplace all of the available mines

To achieve the lowest possible value of 0.0, the MCMS equipment would have to be available but not used. Mines (at least one) would have to be available but not laid. A MCMS BOS value of 0.712 for MSN #18 is the result of a linear combination of the normalized values of the items listed above and indicates an overall use of about 71% of the maximum possible use of the MCMS equipment.

The combined arms measure has values ranging from 0.3679 to 0.9930. This measure is the mathematical variation of BOS percentile values. MSN #10's value of 0.9930 means that the variation between the unit's BOS percentile scores was less than one percent of the possible variation. In other words, in MSN #10 the friendly unit used its weapons from the various operating systems on the battlefield at about the same level. From Table 4.4

we see that each of the BOS percentile scores was under the 17th percentile. The combined arms measure rewards balance between the different BOSs and not necessarily quantity. To attain the lowest combined arms value of 0.0, a unit would have to achieve the maximum variation of BOS percentile scores. Two BOS scores would have to be 0.0 and two would have to be 1.0, showing the maximum possible imbalance between BOSs.

The spatial control measure received values ranging from 0.4924 to 0.8744. To achieve the highest value of 1.0 a commander would have to position his combat power such that it was all concentrated within a designated radius of its center of mass throughout the entire battle. The radius is a function of the range of the weapons available to the unit. A unit could achieve the lowest value of 0.0 by having no overlapping range fans for any of the weapons for the entire battle. In MSN #20 the friendly force controlled its combat power so that less than 13% of the entropy (lack of organization) that could have resulted by allowing the assets to dissipate was measured.

The temporal control measure received values ranging from 0.0038 to 0.0945. The theoretical maximum value of 1.0 for this measure could only be attained by moving a unit's combat power around the battlefield such that no $100m \times 100m$ grid is ever occupied more than once during the battle. The lowest temporal control value could be attained by never moving any combat asset from its originally assigned grid. In MSN #3 the commander temporally controlled his forces so that he avoided almost 10% of the entropy that could have occurred if he had not acted or reacted at all. One would expect a unit in a good defensive posture to have a very low temporal score because the temporal coordination had been done in the planning stages while setting up the defense.

The measure that indicates the level of weapon usage received values ranging from 0.0173 to 0.4002. Weapon use, similar to the combined arms balance measure, is totally dependent on the level of use of each BOS. To achieve the highest value of 1.0, a unit must use, fire, or effectively employ every asset possible, and at the maximum possible rate, for the length of the battle. For firing weapons, the measure assumes the weapon can be fired at its maximum sustainable rate. To achieve the lowest value of 0.0, a unit must not use, fire, or effectively employ any of its assets at any time during the battle. In MSN #18, the friendly force used 40% of its available combat power. The unit fighting in MSN #3 used only 17% of its available assets.

The measure called combat power projection had calculated values ranging from 0.0035 to 0.0706. To achieve the maximum value of 1.0 for this measure, a commander would have to have his highest concentration of combat power positioned so that all of the enemy assets were within this region. A value of 0.0 could be achieved by positioning friendly forces such that no friendly asset could range any enemy asset during the entire battle. This value is quite possible to achieve but would result in having no potential of destroying any enemy assets. Because the maximum value is physically so difficult to achieve, the CPP values for all of the battles are low. In MSN #3, an average of 7% of the total possible enemy combat power was within range of our assets, after normalizing for the highest concentration of friendly combat power each time period.

The measure called invulnerability had values ranging from 0.9581 to 0.9997. This measure is essentially the complement to the enemy's CPP measure, if one were calculated. To achieve the highest possible value of 1.0, a commander would have to avoid occupying any location, with any

asset, that was within range of the enemy's combat power. He would have to maintain this posture for the entire battle. The lowest value of 0.0 could be achieved only by locating the highest concentration of potential enemy combat power for each time period, and moving all of one's assets there. In MSN #5 the commander allowed an average of only 0.03% of his assets to be located within the enemy's range, after normalizing for the enemy's greatest concentration.

4.4 Subjective Battle Scores

Subjective judgments of a unit's conformance to doctrine may be difficult to obtain for several reasons:

- Experts are accustomed to evaluating performance, not doctrinal conformance.
- Experts may differ significantly on how close a given act is to doctrinal guidance. This may be caused by different interpretations of doctrine or by using different subjective metrics of proximity to doctrine.

The measures were developed from first principles. Their definitions were not data driven, except for the availability and form of the data. Because we know what they measure, we must only determine if the subcomponents they are supposed to model are being well represented. To examine the representativeness of the measures, we developed the following procedure:

1. Select the battle (MSN #) corresponding to the highest value for each measure.

2. Select the battle (MSN #) corresponding to the lowest value for each measure.

3. For the set of battles defined by 1 and 2 above, instruct experts to review each battle and rate the friendly force on its degree of conformance to the doctrinal components modeled by the measures. Each battle will be rated only on the components which correspond to either a highest or lowest objective value. Do not inform the participants of the objective values.

4. Test the correlation between the experts' evaluations and the measures' values.

5. This author, who has seen all of the After-Action Reviews, reviewed all of the data, studied the meaning of the measures, and evaluated the units' conformance to doctrine, will also subjectively evaluate the battles.

6. Compare the this author's evaluations to the calculated objective values and the subjective evaluations of the other experts.

The results of this experiment for a given measure can:

1. Indicate support for the objective measure. Support means that a high objective value for a measure and a given battle is usually backed up by a high conformance subjective evaluation, and a low objective value is usually backed up by a low conformance subjective evaluation.

2. Indicate a lack of support for the objective measure. The subjective experts would generally not agree with the either very high or very low

objective measure's value.

3. Show little or no subjective preference for either the highest or lowest objectively measured battles, thus providing no evidence for or against the measure.

For a given measure (e.g., Maneuver), Result 1. above, would indicate that the when the objective measure indicates high conformance. the experts agree. We will check for statistical significance for each of the groups of subjective evaluations using the Wilcoxin Signed Rank test and the 95% level of significance.

Result 2 or result 3 above would be caused by one of the following:

- The explanation of the concept being measured was not completely understood by those who participated in the experiment
- The concept was confounded with other concepts and ideas and was not easily culled from the text, the digital data, and the battle replay by the experts
- The participants use some other easily obtained indicators to make judgments which do not necessarily accurately indicate high doctrinal conformance.
- The mathematical model of the objective measure is not closely related to the doctrinal component being evaluated.

For results of type 2 or 3, we will first analyze the possibility of an objective measure not actually measuring the concept described to the experts.

We will check for any obvious reasons for the participants anchoring themselves to a certain evaluation due to a related indicator. The relationship between the doctrinal concept and the indicator will be addressed.

Based upon the values reported in Table 4.1, the missions listed in Table 4.5 were selected to be reviewed by the experts as representative of battles with either very low or very high values for each of the 12 measures.

Table 4.5: Selection of MSN #'s (battles) Corresponding to High or Low Values

Measure	Low Mission	Value	High Mission	Value
Org Agility	3	.5	5	1.0
Maneuver	12	.0410	10	.3370
Maneuver Weapons	10	.0131	12	.1764
Fire Spt Weapons	3	.0041	2	.6374
ADA Protection	20	.2740	12	.8005
MCMS	2	.1890	18	.7120
Combined Arms	2	.3679	10	.9930
Spatial Control	5	.4924	20	.8744
Temporal Control	13	.0115	3	.0945
Weapons Use	3	.0173	18	.4002
Cbt Power Proj	5	.0035	2	.0516
Invulnerability	13	.9581	12	.9882

Description of the Battle Review

Each of the participants received a two-page explanation of the experiment and of the concepts that would be evaluated. After a participant read the explanation and instructions (both are in Appendix D) a short discussion

served to answer any further questions. Each participant first viewed the replay of the battle. The experimenter ensured the expert knew how to manipulate the controls to be able to obtain the various types of data available. Many times two experts viewed a battle simultaneously. We needed independent answers and stressed this point to the participants.

The participant received a one-page summary of the statistics shown and the comments made during the two-hour After-Action Review that had immediately been conducted following the actual training exercise. The summaries are in Appendix B. This summary was available to the participant during the entire experiment. Also available, by clicking on a menu choice, was the organization of the combat units that had participated in the exercise. The battle itself could be reviewed by either watching the *trace* or the *replay*.

trace This method of reviewing the battle allows the viewer to watch a digital, color representation of the appropriate terrain at NTC while squares, representing individual platforms, appear on the screen. A grid template is superimposed to allow actual identification of the location of a platform and estimation of distances. The trace method places a blue or red square on the screen where it remains for the rest of the battle. A square with white trim represents a position which is currently occupied by an active platform (group of weapon systems). A square without the white trim is simply a 'footprint' showing where the platform had been. The viewer cannot stop a trace of a battle once it has begun. It is an excellent method of watching the flow of the battle since the screen is updated every 5 seconds representing 5-15 minutes of battle time. The viewer is able to judge the movement and

speed of both opponents and watch simultaneous operations occur. It is impossible to discern the type of platform that is represented by each square. Artillery fire is represented by a colored rectangle centered over the appropriate grid and is removed from the screen after the fire's effects have passed. Direct fire rounds are indicated by colored lines connecting the firer and the target. No such line is drawn if the target or the firer is unidentified. Because only matched firing events are visually displayed, many targets may be hit without the viewer's seeing the colored lines. If a tank's fires do not find a target, that too may go unnoticed by the viewer.

replay Each individual platform is represented by a symbol which indicates the type of platform. The battle progresses by manually clicking the mouse button to allow another time step (usually 5-15 minutes) to be shown. Unlike the trace method, footprints are not kept on the screen. The two main advantages of the replay method are:

- Each platform shown can be identified by type and by identification number.
- The tempo of the replay is controlled by the viewer to include stopping the replay altogether.

In addition to the replay and trace capabilities, the digital battle review allows the viewer to review all of the firing events, whether they are matched or not. Both direct-fire and fire support firing events are available. Taken together, the replay, the trace, the review, and the other retrievable data allow the combat analyst's workstation (CAW) to give the viewer easy ways to obtain a great deal of information about a battle.

4.5 Comparison Between Objective and Subjective Results

Table 4.6 through Table 4.8 contain the comparisons between the two evaluation methods. Table 4.9 shows the results of applying the non-parametric Wilcoxin Signed Rank Test to the difference between the subjective evaluations for the battles with the highest and lowest objective values. A complete discussion of the assumptions and derivation of this test can be found in many statistics books, including [Pfaffenberger 87]. The symmetry assumption for the distribution of D_i is met because under the null hypothesis, both component populations have the same mean and unknown densities. The unknown distribution of the difference of two such random variables is assumed to be symmetric. The assumption of continuity for the density of D_i is violated. Because the participants all assigned integer values for their subjective evaluations, D_i, the difference of these evaluations, became a discrete random variable with possible values of -4, -3, -2, -1, 0, 1, 2, 3, 4. This author believes that the integer restriction has only minor impact on the validity of the statistical results of the signed rank test. For each i where $D_i = 0$, the algorithm for the Wilcoxin test reduces n (the number of pairs of random variables) by 1. The fact that the algorithm explicitly provides for ties (i.e., $D_i = 0$) suggests that the author expected ties although ties do not occur when D_i is *truly* continuous.

The a in the subscript of W in the table represents the probability that the W_a value or lower would occur when there is actually no difference between the two population means. In this test, the population means are the unknown, but actual, subjective evaluation population means for the

two battles. If the subjective evaluations indicate an agreement with the objective high/low rankings, Sum(r-) will be equal to or lower than the W_a statistic. If there is not enough evidence to indicate that the subjective evaluations closely follow the objective values, Sum(r-) will be greater than the W_a statistic.

It should be noted that the test was only designed to check for subjective agreement with the objective values when the battles corresponding to the *highest* and *lowest* values are the ones evaluated. The participants did not have the time to evaluate every battle on every measure. Also, the test was designed to give the best possible circumstances for discovering expert support of the objective measures since battles that received close objective values were not tested against the experts. We also do *not* test the question of whether the objective values would necessarily be high if the *subjective* evaluations were known to be high or would the objective values be low if the *subjective* evaluations were known to be low. The issue of statistical correlation of subjective and objective results for battles that are near the middle of the range for a given measure is not explored. The results show that when the following objective measures were either high or low, the experts also produced either high or low evaluations (respectively).

- Organizational Agility
- Physical Agility (Maneuver)
- Fire Support BOS
- MCMS BOS
- Weapons Use

Table 4.6: Subjective vs. Objective High and Low

	Organizational Agility			**Unit's Mobility (Maneuver)**		
	Low Objective Value	High-Low Delta	High Objective Value	Low Objective Value	High-Low Delta	High Objective Value
Expert	**MSN 3**		**MSN 5**	**MSN 12**		**MSN 10**
1	3	2	5	2	2	4
2	1	4	5	1	3	4
3	2	1	3	2	2	4
4	1	4	5	2	1	3
5	3	1	4	3	0	3
6	4	0	4	3	1	4
7	2	3	5	3	1	4
8	1	4	5	1	1	2
9	4	1	5	1	0	1
10	1	4	5	3	1	4
11	1	4	5	3	1	4
12	2	2	4	2	-1	1

	Armor/Infantry			**Fire Support**		
	Low Objective Value	High-Low Delta	High Objective Value	Low Objective Value	High-Low Delta	High Objective Value
Expert	**MSN 10**		**MSN 12**	**MSN 3**		**MSN 2**
1	2	0	2	1	2	3
2	4	-1	3	1	2	3
3	4	-1	3	2	2	4
4	3	1	4	1	2	3
5	3	-2	1	1	0	1
6	4	0	4	1	2	3
7	4	-1	3	1	1	2
8	2	-1	1	1	2	3
9	2	-1	1	1	2	3
10	2	1	3	1	1	2
11	2	-1	1	1	1	2
12	2	-1	1	1	1	2

Table 4.7: Subjective vs. Objective High and Low

	ADA Protection			Engineer Use		
Expert	Low Objective Value MSN 20	High-Low Delta	High Objective Value MSN 12	Low Objective Value MSN 2	High-Low Delta	High Objective Value MSN 18
1	4	-2	2	2	0	2
2	3	-2	1	2	0	2
3	2	0	2	4	0	4
4	4	-1	3	2	1	3
5	5	-3	2	1	2	3
6	2	2	4	1	3	4
7	2	1	3	3	0	3
8	3	-1	2	2	1	3
9	1	1	2	2	-1	1
10	3	-2	1	1	2	3
11	4	-2	2	1	2	3
12	3	-2	1	1	2	3

	Overal Wpns Usage			Combined Arms Balance		
Expert	Low Objective Value MSN 3	High-Low Delta	High Objective Value MSN 18	Low Objective Value MSN 2	High-Low Delta	High Objective Value MSN 10
1	2	0	2	2	1	3
2	1	1	2	2	1	3
3	2	2	4	4	-1	3
4	2	2	4	4	-2	2
5	2	2	4	2	0	2
6	1	2	3	2	1	3
7	1	2	3	3	0	3
8	1	1	2	2	0	2
9	1	2	3	2	0	2
10	1	2	3	2	-1	1
11	1	3	4	2	1	3
12	1	2	3	2	0	2

Table 4.8: Subjective vs. Objective High and Low

	Combat Power Concentration (Spatial Control)			Combat Power Coordination Temporal Control		
	Low Objective Value	High-Low Delta	High Objective Value	Low Objective Value	High-Low Delta	High Objective Value
Expert	MSN 5		MSN 20	MSN 13		MSN 3
1	2	0	2	2	0	2
2	3	0	3	1	1	2
3	2	0	2	2	0	2
4	3	1	4	2	-1	1
5	2	0	2	1	1	2
6	2	0	2	2	0	2
7	3	0	3	1	1	2
8	2	1	3	1	0	1
9	2	0	2	1	0	1
10	3	1	4	2	0	2
11	4	-2	2	1	1	2
12	4	-1	3	2	-1	1

	Defense - Good Position Against Main Attack (Combat Power Projection)			Offense - Main Effort at Enemy's Weak Point Invulnerability		
	Low Objective Value	High-Low Delta	High Objective Value	Low Objective Value	High-Low Delta	High Objective Value
Expert	MSN 5		MSN 2	MSN 13		MSN 12
1	3	-1	2	1	1	2
2	3	-1	2	1	0	1
3	2	2	4	2	0	2
4	3	0	3	1	1	2
5	3	-1	2	2	1	3
6	3	0	3	4	0	4
7	4	0	4	2	0	2
8	1	0	1	1	1	2
9	1	0	1	1	2	3
10	3	-1	2	3	1	4
11	3	-1	2	1	1	2
12	3	-2	1	2	-1	1

Table 4.9: Wilcoxin Signed Rank Test

Measure	Sum(r+)	Sum(r-)	n	$W_{a,n}$	Support Indicated?
Org Agility	66	0	11	14	Yes
Maneuver	44.14	2.857	10	11	Yes
Direct Fire BOS	10	45	10	11	No
Fire Support BOS	66	0	11	14	Yes
Air Defense BOS	12.5	53.5	11	14	No
MCMS BOS	34	2	8	6	Yes
Combined Arms	14	14	7	4	No
Weapons Use	66	0	11	14	Yes
Spatial Control	7.5	7.5	5	1	No
Temporal Control	14	7	6	3	No
Cbt Power Proj	6.5	21.5	7	4	No
Invulnerability	32	4	8	6	Yes

- Invulnerability

The experts' opinions slightly supported **Temporal Control** in that the high–low differences were generally positive but not enough to be statistically significant at the 0.95 level of assurance.

The results for **Combined Arms** and **Spatial Control** were indecisive. The signed rank sums of the positive and negative differences were equal. There was no consensus for these two doctrinal areas for the two battles scored.

Finally, the **Direct Fire BOS, Air Defense BOS, and Combat Power Projection** areas were subjectively evaluated by the experts as opposite the results of the objective measures.

The next table, Table 4.10, shows the results of an expert's opinion who had the complete database at his disposal (this author). He saw all of the actual after-action reviews (AARs), reviewed all of the information available in the battle replay package, and was extremely well-versed in the meaning of the doctrinal areas to be subjectively measured. It was impractical to have each expert spend several hours in a doctrinal briefing explaining the development of the objective measurables, view each two-hour AAR video, and then do a comprehensive battle review for each battle. It was important, however, to have at least one expert who did have this preparation rate each of the battles.

Reviewing the results of Table 4.10, all of the high–low differences were strongly positive (greater than 1) except for **Combat Power Projection** which had a positive difference of only one, and **Combined Arms** which had a negative difference. These results indicate support of the hypothesis that when the objective measures are either high or low, the experts agree

Table 4.10: Comparing Expert vs. Objective Results

Measure	Low Mission	Expert's Evaluation	High Mission	Expert's Evaluation	Expert's Difference
Org Agility	3	2	5	5	3
Maneuver	12	1	10	3	2
Direct Fire BOS	10	1	12	3	2
Fire Spt BOS	3	1	2	4	3
Air Defense BOS	20	1	12	5	4
MCMS BOS	2	2	18	4	2
Combined Arms	2	4	10	2	-2
Spatial Control	5	1	20	5	4
Temporal Control	13	2	3	4	2
Weapons Use	3	2	18	5	3
Cbt Power Proj	5	3	2	4	1
Invulnerability	13	1	12	4	3

with the evaluations. The one negative difference from this author's evaluations indicates that either the objective measure does not truly represent the doctrinal component – combined arms balance – or that such a concept is extremely difficult to accurately estimate by the experts.

4.5.1 Discussion of the Test Results

An important issue in many of the evaluation tasks was the ability of the experts to consistently measure or estimate combat power. While some may not agree completely with Depuy's OLI, there is little subjectivity involved in its calculations. The models involving combat power are therefore consistent, at least in their combat power computations. One of the advantages of the developed measures is the consistency in their combat power estimation. The following paragraphs address issues related to the measures that were not strongly supported by the subjective evaluations.

Temporal Control All of the participants stated that it was difficult to evaluate the amount of **coordination of combat power** the way it was defined [See Appendix D]. The terms 'coordination of combat power' were used in the briefing to the participants, instead of the more technical terms 'temporal control', in an effort to describe the measured battlefield actions more simply. Evaluating a unit's ability to disperse and then concentrate was a new task and possibly somewhat confusing. Not surprisingly, there was some disagreement as to the unit that demonstrated the most coordination.

Direct Fire BOS The Direct Fire BOS objective values were not supported by the subjective ratings. The evaluation was to reflect the expert's

opinion of the volume of fire from Armor and Infantry direct-fire weapons that occurred during the battle. The battle replay software was designed to produce a temporary colored line from the firer to the target. Unfortunately, many engagements occurred without lines being produced for the viewer because either the firer or the target were not known. The viewer would then have to do a complete review of all firing events at the end of the battle. If the expert did not put in the extra effort of reviewing the firing events, he or she would have had incomplete knowledge of the volume of direct-fire. Both battles evaluated for Direct Fire BOS had significant portions of the direct-fire engagements invisible to the superficial viewer. It is very possible that several of the participants made evaluations based upon incomplete evidence. The evaluations made by this author were accomplished after reviewing the entire fire event sequence, after the battle. There was no difficulty in identifying the battle that saw the heaviest friendly, direct-fire volume.

ADA BOS The objective score for ADA usage does not depend upon how often it is fired but upon its positioning with respect to the rest of the unit [See Section 3.6.1]. The expert must check the position of the ADA weapon throughout the battle before determining its 'use'. In the written summaries [See Appendix A], the expert has available information about the *success* of the Air Defense efforts. It is difficult for a 15-year Army combat arms officer to see the number of enemy sorties shot down and the number that were flown and conclude something that is inconsistent with those statistics. In fact, the battle that scored the highest for positioning of Air Defense weapons (Mission 12) had no report of enemy air sorties. The battle that received the lowest objective evaluation for AD positioning (Mission 20), reported 7 out of

10 enemy air sorties shot down by the AD assets. Such knowledge, although accurate, makes it difficult for the experts to evaluate the battle consistent with the objective model. The difference between the two battles' use of ADA assets was very clear in this author's judgement. Mission 12 was rated as a 5 (highest) and had its ADA assets spread well throughout the battlefield. Mission 20 was rated as a 1 (lowest), and kept its ADA assets in very close, protecting very little of the friendly force's assets.

Combat Power Projection The Combat Power Projection (CPP) measure was presented to the experts as a defensive concept in which it was desirable to have a relatively strong position against the enemy's main attack. The calculations for this measure computed the amount of coverage of the enemy assets with respect to the ranges of friendly weapon system platforms. However, instead of evaluating the actual positions of enemy assets vs. the capability of friendly assets throughout the battle, it appears that a majority of experts were biased by the statements in the summaries of the after-action reviews. The summary for Mission 5, a defense, indicates a high level (71%) of fire support effectiveness, good coordination, and overall good planning and execution. The value for the CPP measure was the lowest of the defensive battles. Although the words do not address the issue of adequately opposing the enemy's main attack, the positive tone of the summary combined with its availability would tend to bias the evaluator [Khaneman, Slovic, and Tversky 87] Chapter 11. The summary for Mission 2, also a defensive battle, indicated low agility, "movement was not coordinated", and "all companies had massing problems". Mission 2 had the third highest value of the Combat Power Projection measure of all 13 battles and

the highest score for the five defensive battles. This author rated Mission 2 higher than Mission 5 in CPP, consistent with the objective measure. Apparently, the disagreement between the experts' subjective evaluations and the objective CPP scores is not due to an incorrect derivation of the CPP model but either a miscommunication of the concept to the experts or a bias of the experts due to the summaries of the missions.

Combined Arms Balance In the case of Combined Arms Balance, both the experts and this author arrived at a different evaluation than the objective measure's relative value. The 12 experts that participated in the exercise were inconsistent in their evaluation of both the Air Defense BOS and the Direct Fire BOS (already addressed above) compared to the objective measures' values. Given this disagreement of the *input* values, one would not expect there to be consistent agreement between the subjective and objective Combined Arms Balance evaluations.

By design, this author was knowledgeable of the variation function used to produce the Combined Arms Balance score. Also, the results showed that this author's scoring of the individual BOSs was consistent with the objective scores. Therefore, the disagreement of the Combined Arms Balance results between this author's subjective measure and the objective measure was caused by either miscalculation or a different idea of balance.

Difficulty in Calculating Variance Kahnemann and Tversky addressed this issue. It appears that humans are not good at either predicting or estimating variance. [Khaneman, Slovic, and Tversky 87] The calculations involved in computing variance are too complicated to be internalized and,

therefore, subjectively intractable. For Combined Arms, not only is the calculation $\frac{\sum_{i=1}^{4}(CA_i - CA_{avg}^2)}{n}$ difficult, but it is made even more difficult by requiring the CA_i scores to be normalized. It is therefore not surprising that this author had difficulty in evaluating the Combined Arms Balance consistent with the objective measure's values.

Different Idea of Balance The group of twelve experts were not told to estimate the *variance* of the individual BOS scores. We instructed them to evaluate the balance of the friendly force's use of the combined arms. The underlying model in each expert's idea of balance may not have been to measure variance of the individual normalized scores. Balance may have conveyed the idea of the 'right' amount of each BOS, or even 'enough' of each BOS. What is subjectively the right amount for *each BOS*, for *each expert*, for *each battle* would be difficult to model and not the purpose of this research. If 'right amount' refers to the amount that results in success, then the definition is a useless one for diagnostic purposes. The idea of 'enough' may be just as vague or it could be the key to the experts' evaluations. Perhaps there is a threshold for each BOS, less than which constitutes risking failure in battle. If there is such a level, perhaps it can be modeled for each BOS. One can show mathematically that ranking battles by the degree BOS thresholds are satisficed differs from ranking the same battles by the size of the variance.

There is a counterintuitive aspect to the Combined Arms Balance measure. Mission 2, compared to Mission 10, had a higher objective value calculated in the Direct Fire BOS, and a much higher objective value in the Fire Support and ADA measures. However, Mission 10 had the highest value for the overall Combined Arms Balance measure, of the 13 measured battles

and Mission 2 had the lowest value. Given the calculated values and relative standings of the different BOSs, one would naturally select Mission 2 over Mission 10 for better balance. It appears that balance is not usefully captured by variance but by some other mathematical model – possibly the degree of BOS satisficing discussed above.

4.5.2 Summary of the Results

We selected thirteen battles of battalion-level Infantry task-force size from the large database of NTC Force-on-Force battles. We calculated twelve measures for each of these battles. We then selected twelve experts to watch a digital replay of eight of the battles and then rate the battles in selected doctrinal areas. The results indicate that for the following measures, the experts tend to qualitatively agree with either the very high or very low objective measure values.

- Organizational Agility
- Physical Agility (Maneuver)
- Fire Support BOS
- MCMS BOS
- Weapons Use
- Temporal Control
- Invulnerability

The results were indecisive for the objective measures of:

- Direct Fire BOS
- ADA BOS
- Spatial Control
- Combat Power Potential

The results for Combined Arms Balance showed a lack of support.

This author has 17 years experience in the US Army. Half of that time was spent with tactical units. The experience in the Army's Field Artillery, the tapes of the AARs, and a thorough knowledge of the computer interface were all positive attributes for any expert that wanted to participate. After having designed the doctrinal conformance structure and spending considerable time reviewing the battle replays and exploring the database, the battles for the Combined Arms Measure were evaluated consistent with the other twelve participants. Only one measure, Combined Arms Balance, was not qualitatively supported by the author's subjective evaluations.

CHAPTER 5

Summary and Conclusions

5.1 Summary

This research had three objectives:

- Analyze the role of doctrine in achieving victory in battle, and the need for measuring conformance to doctrine.
- Analyze one model of doctrine to determine the link between high-level concepts and behavior on the battlefield. We chose the Tenets of Army Operations: Agility, Initiative, Depth, Synchronization, and Versatility.
- Develop measures of conformance to components of doctrine that use available battlefield data and rate high in parsimony, generalizability, and fidelity.

Chapter One established that success in a battle does not indicate that the doctrine was good. Nor does success mean that we complied with doctrinal principles. If we know the level of doctrinal conformance *and* the level

of success achieved in many battles, we can begin to analyze the effect of doctrine on the outcome of battle.

In Chapter Three, The techniques needed to analyze doctrine were developed. After concluding that a hierarchical approach to the analysis would be best, five criteria were developed for judging the best group of subcomponents for each component in the doctrinal hierarchy.

- Applicability
- Comprehensiveness
- Parsimony
- Orthogonality
- Measurability.

The top-down analysis continued until the components being analyzed could be explicitly modeled using observable battlefield data. The complete analysis methodology was demonstrated for two (Agility and Synchronization) of the five tenets of Army Operations. A preliminary analysis was performed on another two tenets – Initiative and Depth. The fifth tenet – Versatility – was not addressed.

The analysis of **Agility** produced the following hierarchical structure:

- **Mental Agility**
  - Speed of Decision Making
  - Number of Changes to the Plan
- Organizational Agility

  - Speed of Preparing FRAGOs
  - Speed of Preparing OPORD

- **Physical Agility**
  - Maneuver

A preliminary analysis of **Initiative** produced the following components:

- Freedom of Action
- Offensive
- Risk-Taking
- Controlling the Terms of Battle

A preliminary analysis of **Depth** produced the following components:

- Planning
- Spatial Depth
- Temporal Depth
- Reserves

A complete analysis of **Synchronization** produced the following hierarchical structure:

- **Combined Arms**
  - Maneuver (Direct-Fire)

- Fire Support
- Air Defense
- Mobility, Countermobility, Survivability

- **Control**
  - Spatial Control
  - Temporal Control

- **Weapons Usage**
  - Maneuver (Direct-Fire)
  - Fire Support
  - Air Defense
  - Mobility, Countermobility, Survivability

- **Doctrinal Positioning**
  - Combat Power Projection
  - Invulnerability

The subcomponents of Agility and Synchronization depend principally upon the following observable data:

- Time and Location of Assets
- Type of Assets
- Characteristics of the Assets

- All Firing Events

- Timing of Critical Decisions

- Timing of the Published Orders

- Use of MCMS assets

The required data named above are all feasible based upon current technology. Some of the data are not yet available because the need for compiling and storing them had never been identified [Holz 94]. The data not available for this study include the time used for decision-making, the number of operations plan changes, the time to prepare FRAGOs, and the evaluation of engineer assets in the offense. All of the other data required by the measures are available through the ARI-POM database [Holz 94] or were compiled through additional research.

Model building began when the analysis determined that the components were measurable. Each proposed model was judged against standards of parsimony, generalizability, and fidelity. Several constructed models require few calculations (e.g., Organizational Agility), while others are quite computationally intensive (e.g., Spatial Control). The reader is referred to Section 3.7 for short summaries of all 14 measures. There is an example scenario in Section 3.8 that demonstrates the actual calculations needed for each of the measures of doctrinal conformance.

After building a hierarchical structure of Army Operations doctrine and constructing models of the doctrinal subcomponents using mathematical functions of battlefield data, the next step was to test the models for consistency with experts' views. Previously fought NTC Force-on-Force battles

(see Section 4.3) were selected. Each battle was between a friendly (Blue) battalion-level Mechanized Infantry task force which used AirLand Battle doctrine and an opposing force (Red or OPFOR) that used Soviet-style doctrine. After controlling for factors such as unit type, unit size, and mission type, thirteen battles were selected. Objective values for the measures were calculated for each of the battles. The results are in Tables 4.1 through 4.4 in Chapter 4.

Each measure that was modeled included a normalization procedure to adjust for assets available, the duration of the battle, and OPFOR capabilities. Each raw measure intrinsically has a true maximum and minimum based on mathematics, physics, or the realities of combat. All of the objective values of the measures were normalized to have a maximum value of 1.0 and a minimum value of 0.0. The means and ranges of the normalized values were difficult to predict. The means ranged from 0.0308 for Combat Power Projection to 0.9864 for Invulnerability. The numerical range of scores also varied greatly. Invulnerability values ranged from 0.9581 to 0.9997, a spread of only 0.0416. Combined Arms values ranged from 0.3679 to 0.9930, a spread of 0.6251 (see Table 4.1).

The results of an evaluation sheet given to 12 experts (experienced Army officers) are contained in Table 4.6 to Table 4.8. Appendix D contains a sample evaluation sheet and the briefing sheet given to the participants. The experts were shown replays of the NTC battles that represented the lowest and highest objective values for each of the measured areas. We compared the experts' evaluations of the doctrinal components as seen by the battlefield behavior to the objective values calculated using the measures developed for the same doctrinal components. The measures of Mental Agility, MCMS

(Offense), and part of Organizational Agility could not tested due to lack of data. The results of the test are described in detail in Section 4.5.

Using the non-parametric Wilcoxin Rank Sum Test to compare experts' subjective evaluations of the battles corresponding to those with the highest and lowest calculated objective values, we found that with the objective measures of Organizational Agility, Physical Agility, Fire Support, MCMS (Defense), Weapons Usage, and Invulnerability, when the objective values were high, the experts' evaluations were also high. Similarly, when the objective values for these measures were low, the experts' evaluations of conformance to doctrine were low. There was some indication that the experts agreed with the high-low objective values assigned to Temporal Control but the Wilcoxin test showed a less than 95% level of significance. The results for Combined Arms and Spatial Control were indecisive. Finally, there was a general lack of agreement among the experts with the high or low objective values for the measures of Direct-Fire (Maneuver), Air Defense, and Combat Power Projection.

Evaluations of the battles by this author are in Table 4.10. He had complete knowledge of the database used in the battle's replay, had viewed the complete, 2-hour, After-Action review, was knowledgeable of the measures and constructed models, and viewed the battle replays of each battle several times. One could say the 'fog of war' had been lifted for him. His evaluations served as benchmarks indicating the possible subjective results if all information had been available, understood, and used by the other experts. His evaluations were consistent (i.e., the battle he evaluated as having the higher level of conformance to a given component also had the higher objective value) with the objective values for all measures except Combined Arms

Balance.

5.2 Conclusions

Several conclusions can be drawn concerning the three research objectives.

1. Six objective measures of conformance to Army Operations doctrine have been derived from the components of the tenets of Agility and Synchronization. They have been calculated, demonstrated, and evaluated. The subjective evaluations of Physical Agility, Organizational Agility, Fire Support, MCMS (Defense), Weapons Usage, and Invulnerability agree with the high or low objective values produced by the algorithms develooped for these components of Army Operations doctrine.

2. Another five objective measures of conformance to Army Operations doctrine have been developed, calculated, and demonstrated. The evaluations by this author support the high and low objective values produced by the algorithms but the twelve experts' evaluations did not consistently agree with the objective values. These measures are Direct-Fire, Air Defense, Temporal Control, Spatial Control, and Combat Power Projection.

3. There is a need for modeling doctrine and measuring conformance to it. Logically, it is difficult to draw meaningful conclusions about the success of certain battles and the part doctrine played in those successes without knowledge of the level of doctrinal conformance. It is difficult

to improve doctrine and even more difficult to show improvement has occurred without conformance measures.

4. High-level doctrine can be vague and general, and therefore, not easily analyzed or modeled. Throughout the analysis, the five characteristics of applicability, comprehensiveness, parsimony, orthogonality, and measurability were valuable in assessing the validity of the structure. The analysis helped to define more rigorously each of the terms used daily in doctrinal discussions. For instance, agility no longer connotes a single idea of flexibility or nimbleness (each of which are equally vague), but *three* concepts of mental, organizational, and physical agility. Each of these concepts also has a more rigorous meaning, and can in fact be modeled using battlefield data. This work should be valuable in helping teachers, developers, and users of doctrine to be more explicit and to link low-level doctrinal advice to higher-level principles.

5.3 Recommendations

Based upon the research contained in this dissertation and the conclusions above, there are two major recommendations:

1. The six measures that were supported by the subjective evaluations should be used by the U.S. Army. The six measures are Physical Agility, Organizational Agility, Fire Support, MCMS (Defense), and Invulnerability. There are three ways in which these measures of doctrinal conformance should be used:

- Post-exercise reviews. Commanders and staffs can see objective, diagnostic evidence of doctrinal conformance. They will know how their actions relate to the tenets of Army Operations and what actions to train on to affect improvement.

- Monitoring behavior during a battle. Commanders will be able to monitor such behavioral measures as organizational agility and invulnerability. They can order changes in a unit's behavior before a critical point in the battle if very low values are calculated for the doctrinal measures. The measures would play the role of a decision support system. As Distributed Interactive Simulation (DIS) changes the manner in which the U.S. Army trains, these measures should also be valuable for use in simulations and war games.

- Doctrinal improvement. As changes in technology, politics, and power change the face of combat, doctrine will change too. These measures will allow writers of doctrine to evaluate new doctrine by testing conformance vs. outcome in training battles already fought. Many of the measures developed here will be reusable in modeling components of the new doctrine.

2. Several data types should be added to the large NTC database and other minor changes should be made to the distribution of the battelfield data. The increased number of data types would allow for richer models and should not significantly increase the cost of data collection.

   - Number of courses of actions presented to the task force commander before the final course of action decision is made. This

information is probably already observed and may be recorded by the observers but just not entered into the database.

- The time of the receipt of critical pieces of information to which the commander and staff have to react. This information is not currently being recorded but is available and would help in modeling both Mental and Organizational Agility.

- The number of rounds actually fired during a fire support mission. Currently, the number of rounds must be assumed based upon either doctrine or what was agreed upon before the battle.

- Different symbols for the minefields and the persistent chemical attacks should be developed for the computer replays. The same color and pattern make it difficult for the experts to evaluate friendly actions.

- An evaluation of the use of MCMS assets in the offense. Actions which include MCMS assets are breaching minefields, clearing obstacles, and crossing rivers, lakes, and streams.

- The status of tactical communications at all levels from platoon to brigade. This could be accomplished by monitoring the nets and determining when a commander or staff organization loses communication with a subordinate or higher unit – and when communications are reestablished.

5.4 Contributions

1. The most important contribution has been the development of six new objective measures of conformance to doctrine

2. Six other objective measures of conformance to doctrine were developed which, with more testing, should also move the field of doctrine development forward.

3. The theoretical formulas were operationalized and coded into working FORTRAN IV programs to be used in future studies (see Appendix B).

4. A hierarchy that formally models the interconnectivity between the major factors of combat, and establishes their relationship with the top goal of victory has been developed.

5. A value of combat power was calculated for each platform and weapon system on the battlefield using Dupuy's formulas for OLI (see Appendix C).

6. There is now a range of normalized scores established for all of the measures except Mental Agility and MCMS (Offense).

7. A blueprint for analysis has been established. Agility and Synchronization were completely analyzed and preliminary analysis was accomplished for the tenets of Initiative and Depth (see Section 5.5.1).

8. A list of missing but required data items has been established for improving the utility of the NTC database and data collection efforts.

9. Towards the goal of determining the relationship between conformance to Army Operations doctrine and success on the present battlefield, a great deal of the analysis, modeling, and data collection has been accomplished (see Section 5.5.3).

5.5 Future Work

As evidenced in the literature search of Chapter Two, very little has been written in the area of measurement of doctrinal conformance. The work done by Larsen, Kemple, Lamont, and Dyer helped in the analysis of Synchronization and will be valuable for developing graphical representations of doctrinal conformance for each measured area, if desired. This dissertation is a step towards being able to measure conformance to many doctrines and for all four services in the Armed Forces. One of the ultimate goals is to provide doctrine developers a more scientific method of improving doctrine. The second goal of giving unit trainers and commanders definite direction for future training based upon the observed actions at places like the NTC should make visits to Combat Training Centers more valuable. In the following three sections, future work is recommended that builds on the work in this dissertation.

5.5.1 Completing the Work Related to the Tenets

More work is needed to develop a complete set of measures for the tenets of Army Operations. First, an alternative to the concept and model used for Combined Arms Balance should be built. Second, obtain the data that was not available to complete the study for the Mental Agility and Organizational Agility and MCMS (Offense) models. Third, the measures that were not strongly supported by the 12 experts but were supported by the evaluations of the 'true expert' need further testing. These measures include Direct-Fire, Air Defense, Spatial Control, Temporal Control, and Combat Power Projection. Fourth, analyze the components and then model the sub-

components related to the final two tenets of Initiative and Depth. I suspect some of the models developed for Agility will be useful in modeling the closely related tenet of Initiative. Similarly, some of the models used for Synchronization may be useful in building models for the subcomponents of Depth. Because the tenets were not developed through the same type of analysis used in this research and have not necessarily passed the orthogonality test, some degree of overlap of ideas between the tenets is expected.

5.5.2 Similar Research on Other Doctrines

The tenets of Army Operations are but one method of organizing doctrine. Using this work as a blueprint or guideline, other doctrines should be analyzed, the most important being the Principles of War [Fuller 21] and the Dynamics of Combat Power [FM 100-5 93].

Because of the initial work done with the tenets of Army Operations, there will be a set of models that relate the behavior of a unit on the battlefield to the tenets of Army Operations. It appears that there is a relatively small set of significant actions on the battlefield, and it is hoped that this initial set of models (measures based on battlefield actions) will greatly assist those doing similar research for other doctrines.

Other doctrines, perhaps not related to combat such as in politics or in industry and management, may be analyzed using the same techniques. Each general area will have its own relatively small set of measurable behaviors that relate to the principles peculiar to that doctrine. Doctrinal principles such as Agility in industry, Power-Down in management, and Quality Improvement in many large organizations could all be theoretically analyzed and modeled.

5.5.3 Conformance vs. Performance

Since the ultimate goal of combat and thus the goal of doctrine is victory in battle, the relationship between doctrinal conformance and combat success is important. The data is available for many measures of combat success that are currently being used: [Morse and Kimball 70],[Pawlowski 93]

1. Exchange Rates
2. Degree of mission accomplishment
3. Percent of force remaining, independent of enemy force
4. Amount of ground taken (lost)
5. Some weighted combination of 1–4

Because the relationships between measures of doctrinal conformance and various measures of combat success are not necessarily linear nor convex, Artificial Neural Networks (ANN) appear to be one method of examining them. ANN's have been used to model complex, multiple-input, multiple-output systems very successfully [Bartlett 94],[Knepell 90]. Because of the work done during the analysis phase of our research, the measures are tied closely to the components of the tenets of Army Operations doctrine.

If a *linear* model is to be used, Structured Equation Modeling may be the proper approach [James, Mulaik, Brett 82]. With known measures of battlefield success and known measures of conformance to doctrine, most of the quite restrictive assumptions of Structured Equation Modeling (a subset of factor analysis) are met.

Whether the relationships can be modeled using linear or nonlinear models, it is important that this research be taken to its next step. Money, time, resources, and lives all rely on the U.S. Army's developing, teaching, and implementing the best possible doctrine.

Appendix A

The National Training Center Database

A.1 Introduction

This appendix contains the background and explanation of the data used in the calculations in Chapter Four. The data were obtained through various modes of data collection during live training battles fought at the National Training Center (NTC) at Ft. Irwin, Calfornia. The NTC is a unique training base that was designed solely to offer the combat unit a realistic environment in which to train. The post is large enough to allow several battalion sized forces to train in varied terrain, against mixed forces that use doctrinally authentic tactics. One part of the training consists of a live fire battle during which pop-up targets, representing opposing forces' weapon systems, appear in tactically correct positions. The friendly forces must react quickly and appropriately and be accurate in their fire. Although the represented enemy appears, it does not fire back. It's tactics are very limited as is the terrain over which the battle occurs.

The second form of training is in the 'force-on-force' region which is much larger than the live fire area. The terrain is varied, the possible missions are

many, and the enemy can move. Both forces have the capability of firing at the other force. Each weapon system has an electronic transmitter and receiver. The system of transmitters and receivers allows a soldier to know when his or her weapon system has been hit. For the appropriate weapons, smoke and noise follow a successful firing. The accuracy of the transmitters closely approximates that of the weapons being fired. The immediate feedback enhances realism of the training environment. During movement, every weapons platform is tracked and the position, time, and status of the system is recorded. The status may be active, destroyed, or immobilized.

All of the information on each weapon system is stored, analyzed for an immediate after-battle discussion, and then sent to the Army Research Institute at Presidio of Monterey in California for long term storage. The after-battle discussion is called an After-Action Review (AAR). A combat arms officer, as chief of the observer-controller team, runs the discussion. Usually a video tape is shown to a group of key leaders from the unit being trained. The tape contains short clips of actions that occurred during the battle. An organized discussion follows that touches on the key aspects of the battle. The unit leaders all have a chance to talk about what happened, why it happened, and whether it could have been done better. The review is filled with valuable comments, summary statistics, and comments/evaluations from the observers/controllers (OCs).

Finally, a take-home package, which contains all of the content of the AARs, along with computer animation disks showing the conduct of the battle, is available to the unit's commander. Other statistics not discussed or only briefly referred to in the AAR are also included. The packages' main purpose is to give the unit something solid upon which to build their training

program for the next 12 months.

A.2 On-Site After Action Reviews

Below is a collection of notes taken from the observation of 21 AARs coinciding with the 21 battles, from FY 92-93, whose data will be used in the test portion of this research. All of the battles reviewed are of the force-on-force type of battle in which there are actual enemy platforms maneuvering on the battlefield. The mission number maps to a true mission number assigned by the NTC controllers. The original mission numbers are sensitive and will not be released without written approval of the Commander, Center for Army Lessons Learned (CALL), Ft. Leavenworth, Kansas, or his designated representative (Phone DSN 552-3035/ COM 913 684-3035). The summaries at the end of each mission review were written by the author of this research as an attempt to summarize two hours of video-taped discussion by both the observers and the participants.

Mission -- 1 Mission Statement -- Movement to Contact

Area of Opns -- Whale Gap

Time Usage -- Bn Order issued at 1/4

Co's 1/3 made 1/3 rule

Major Weapons Results

Friendly	Start	Finish
M1	25	2
M2	23	0
M3	4	2
Vul	4	2
Stinger	3	2

Fire Support Effectiveness

Category	Artillery
Total	594
Eff	102
Supp	120
Ineff	372
% eff or supp	37%

Summary

Synchronization needs work as far as bringing in other than directfire weapons systems Engr, Ada, Fa, Air, Helicopter. Trouble massing fires (B Tank) Great massing for A Mech.

Overall good massing of direct-fire weapons. Good Agility for Air Defense, companies. Too much decentralization - cdr's intent not well enough known. Information Dissemination not up to standards. Good speed. Objective of attack vs. the centroid of the enemy. (Mission is to destroy the enemy).

Mission -- 2 Mission Statement -- Defend in Sector

Area of Opns -- Whale and Valley of Death

Time Usage -- Bn Order issued at 1/2

Co's 3/5's made 1/3 rule

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	25	3	T72	44	23
M2	21	1	BMP	110	45
M3	4	0	AT-5	7	5
Vul	5	2	BRDM	14	9
Stinger	4	4			

Fire Effectiveness

Type	Rds/Kill
120mm	7
25mm	121
TOW	28 (4 is considered good)

Engr Equip	Poss Hrs	Poss Psns	Actual Hrs	Actual Psns
ACE	150	50	33	11
SEE	50	50	12	11

Only 50% of positions dug to standard.

Summary Notes:

Counter recon was very good. Poor dissemination of Cdr's intent and of all information during the operation. Poor target acquisition effort. Obstacles not coordinated with fires, indirect and direct. All companies had massing problems - concentration. Agility rated as LOW. Couldn't get to the right position fast enough. Movement was not coordinated.

Mission -- 3 Mission Statement -- Movement to Contact

Area of Opns -- Whale Gap/OP1

Time Usage Bn Order issued at 2/3

Co's 4/5 made 1/3 rule

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	25	1	T72	25	20
M2	20	1	BMP	27	11
M3	5	2	AT-5	11	8
Vul	5	4	BRDM	50	46
Stinger	4	1			

Summary Notes

Main effort not weighted. No fire support coordination (Synchronization) Trouble massing effects. Poor planning and time management. Didn't maximize range advantage. Poor intelligence. Didn't get a chance to use agility. Poor anticipation. Command and control were the main weakness.

Mission -- 4 Mission Statement -- Deliberate Attack

Area of Opns -- Whale Gap

Time Usage Bn Order issued at 1/2

Co's 5/5 made 1/3 rule -- Very good preparation

Major Weapons Results

Friendly	Start	Finish
M1	25	0
M2	25	9
M3	6	3
Vul	5	3
Stinger	4	2

Fire Support Effectiveness

Category	Arty
Total	15
Eff	2
Supp	6
Ineff	3
% eff or supp	53%

Air Battle Red lost 6/8 sorties, Blue lost 1/6 sorties

Summary Notes

2 Fratricides - poor low level coord. Overall excellent

Synchronization. Great rehearsals, good plans with options built in. Good ADA reaction and no Mortar/Artillery losses. Command and control good during battle except for commo problems. Problems massing because units split up.

Mission -- 5   Mission Statement -- Defend In Sector

Area of Opns -- Whale Gap/NoName Pass

Time Usage   Bn   Order issued at 1/6

Co's 5/5 made 1/3 rule

Major Weapons Results Direct-Fire Effectiveness

Friendly	Start	Finish	Type	Rds/Kill
M1	24	0	120mm	6
M2	23	2	25mm	210
M3	3	2	TOW	14
Vul	5	5		
Stinger	4	2		

Engr Equip	Poss Hrs-	Psns	Actual Hrs-	Psns
ACE	162	64	108	58
SEE	82	81	20	20

Standards		Dug	To Standard	Not Used
	Vehicle	58	33	3
	Crew	20	12	0

Only 1/2 of time used to emplace 2614 out of 3414 mines

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	2166	1296

Eff	444	30
Supp	1092	702
Ineff	730	584
% eff or supp	71%	56%

Air Battle Red lost 7/10 sorties, Blue lost 5/6 sorties

Summary Notes:

3 Fratricides. Denied information to enemy. Good coordination, except for FASCAM and mines not covered by fires. Overall good plan and execution.

Mission -- 6 Mission Statement -- Movement to Contact

Area of Opns -- Whale Gap

Time Usage Bn Order issued at 1/3

Co's 5/5 made 1/3 rule -- Good Preparation

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	26	0	T72	10	9
M2	28	4	BMP	60	35
M3	6	3	AT-5	3	3
Vul	3	3	BRDM	7	7
Stinger	4	1			

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	1316	0
Eff	2	0
Supp	706	0
Ineff	608	0
% eff or supp	53%	0

Air Battle Red lost 6/6 sorties, Blue lost 0/2 sorties

Summary Notes:

Main problems were massing fires and Fire Support Usage

FS Coordination line was used improperly and hurt control.

Bad agility - Mission continued AFTER new and important

info was available. Poor task/purpose for the TF and for the companies. Noone had 'kill' Mission, all had 'fix' Mission. Decision Loop time was too long. Didn't anticipate or take the initiative.

Mission -- 7 Mission Statement -- Defense in Sector

Area of Opns -- Whale

Time Usage Bn Order issued at 4/9

Co's 3/5 made 1/3 rule

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	28	4	T72	41	15
M2	22	3	BMP	116	37
M3	4	0	AT-5	7	5
Vul	3	1	BRDM	13	10
Stinger	4	3			

Engr Equip	Poss Hrs	Poss Psns	Actual Hrs	Actual Psns
ACE	155	78	101	55
SEE	62	62	20	40

Engr Standards	Type	# Dug	To Standard	Not Used
	Veh	55	14	3
	Crew	40	6	10

Fire Support Effectiveness Direct-Fire Effectiveness

Category	Arty Rds	Mtr Rds	Type	Rds/Kill
Toal	3400	1000	120mm	82
Eff	494	252	25mm	180

Supp	704	486	TOW	10
Ineff	2206	193		
% eff or supp	35%	79%		

Air Battle Red lost 4/8 sorties, Blue lost 3/6 sorties

Summary:

Poor rehearsals. No fire planning ADA didn't follow plan as written. Fratricide. High level coordination was poor. A CO given too many Missions. Engr and S-3 had poor coordination. Obstacles not included in fire plan. Nothing happened on time.

Mission -- 8 Mission Statement -- Deliberate Attack

Area of Opns -- North of Red Pass

Time Usage Bn Met the 1/3 rule

Co 5/5 met the 1/3, 2/3 rule

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	27	15	T72	10	1
M2	19	15	BMP	11	1
M3	5	2	AT5	4	3
Vul	4	4	BRDM	18	3
Stinger	4	4			

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	120	60
Eff	0	60
Supp	0	0
Ineff	120	0
% eff or supp	0%	100%

Air Battle Red lost 0/0 sorties, Blue lost 0/6 sorties

Summary Notes:

Engineer use good - good breech. Poor ADA reaction and C&C. Artillery was ineffective - poor coordination. Air and Arty

had tough time. CSS very poor. FSO and S3 didn't know of changes or learned too late. Synchronization was poor but excellent agility at lower levels. No weighting or prioritization of fires.

Mission -- 9 Mission Statement -- Deliberate Attack

Area of Opns -- Whale/OP1

Time Usage	Bn	1/2 instead of 1/3
	Co	2/5 met the 1/3 rule

Overall poor preparation (TMs B and E could not prepare).

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	22	1	T72	49	37
M2	21	1	BMP	73	41
M3	5	0	AT-5	6	5
Vul	3	1	BRDM	8	8
Stinger	4	3			

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	395	0
	Eff	0	0
	Supp	68	0
	Ineff	327	0
	% eff or supp	27%	0%

Air Battle Red lost 1/8 sorties, Blue lost 0/6 sorties

Summary Notes:

Battle tracking didn't happen. Poor agility because of

poor decision loop. Intell didn't get to cdr with recommended courses of action. Didn't focus on the objective. Massing was poor. Too decentralized.

Mission --10 Mission Statement -- Deliberate Attack

Area of Opns -- Whale

Time Usage	Bn	4/9 instead of 1/3
	Co	5/5 made 1/3 rule-probably at 1/4

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	22	2	T72	28	11
M2	20	5	BMP	27	10
M3	5	0	AT-5	5	2
Vul	4	0	BRDM	8	5
Stinger	3	1			

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	522	155
	Eff	28	25
	Supp	32	50
	Ineff	462	80
	% eff or supp	11%	48%

Air Battle Red lost 0/8 sorties, Blue lost 6/8 sorties

Summary Notes:

Good Reporting - need work on indicators and decision points. Good integration of Intell. Overall good

planning - execution needs work. A Co pushed into kill sac. (Wrong place, wrong time). Need better intell. analysis. Spt Fires not synchronized with maneuver. FASCAM and spt fires planned but not executed.

Mission --11 Mission Statement -- Defense in Sector

Area of Opns -- Whale

Time Usage	Bn	at 1/2 instead of 1/3
	Co	5/5 met the 1/3, 2/3 rule

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	26	7	T72	39	7
M2	18	0	BMP	107	24
M3	6	3	AT-5	9	0
Vul	3	2	BRDM	17	14
Stinger	4	3			

Decentralized ADA control

Engr Equip	Poss Hrs-Psns		Actual Hrs-Psns	
ACE	124	82	88	57
SEE	62	62	4	4

Average Posn/Hour ACE -- 1.7 / hr SEE -- 1.0/hr

Only 895 out of 4885 mines available were emplaced.

Engr Standards	Type	Dug	To Standard	Not Used
	Veh	57	30	0
	Crew	4	0	0

Fire Support Effectiveness			Direct-Fire Effectiveness	
Category	Arty Rds	Mtr Rds	Type	Rds/Kill
Total	166	765	120mm	97
Eff	216	0	25mm	180
Supp	664	180	TOW	2.9
Ineff	786	586		
%eff or supp	53%	23%		

Air Battle Red lost 0/6 sorties, Blue lost 3/6 sorties

Summary Notes:

Good Synchronization (.6-.7). 2 Fratricides-indicates problems with coordination and fire control. Good use of FA and mortars. We canalized him and then we had NO prepared positions -planning problem (depth). Good reaction to enemy actions. Good ammo prestocking -poorly dug positions.

Mission --12 Mission Statement -- Deliberate Attack

Area of Opns -- Red Pass

Time Usage	Bn	1/2 instead of 1/3	Good Warning Order
	Co	4/5 beat the 1/3	Good Prep, Poor Engrs

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	27	4	T72	14	11
M2	22	7	BMP	61	49
M3	2	2	AT-5	6	0
Vul	3	0	BRDM	6	2
Stinger	4	2			

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	1255	216
Eff	144	0
Supp	218	54
Ineff	956	162
% eff or supp	28%	25%

Summary Notes:

Poor agility within OWN situation. Problems with detecting and acquiring targets. Poor intell. FS never massed fires. Very poor synchronization both in plan and execution. FISTS and Scouts, and ADA all in decentralized mode. Tried

deception with smoke.

Mission -- 13 Mission Statement -- Movement to Contact

Area of Opns -- Whale Gap

Time Usage	Bn	Met the 1/3 rule	
	Co	4/5 met the 1/3	Standard prep - good (85%)

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	26	5	T72	10	8
M2	28	6	BMP	48	26
M3	6	2	AT-5	5	2
Vul	3	0	BRDM	12	3
Stinger	5	5			

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	570	150
	Eff	108	0
	Supp	288	0
	Ineff	180	150
	% eff or supp	69%	0%

Air Battle Red lost 0/2 sorties, Blue lost 0/0 sorties

Summary Notes:

Poor control of ADA and no Air Mission. POOR agility.

Didn't react to new enemy posn, poor commo, no frago

issued when enemy was found. Wrong movement type and formation, poor control. Poor dispersion. Coordination very poor.

Mission -- 14   Mission Statement -- Hasty Attack

Area of Opns -- Crash Hill

Time Usage Bn   at 1/4 instead of 1/3

Co 5/5 met the 1/3 rule Prep was excellent, except for the scouts.

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	20	0	T72	28	24
M2	20	0	BMP	51	28
M3	4	0	AT-5	5	2
Vul	3	0	BRDM	9	4
Stinger	5	1			

(Centralized ADA control)

Air Battle   Red lost 6/12 sorties, Blue lost 0/8 sorties

Summary Notes:

S-2 has good anticipation/use of Intell. Poor target acquisition. TF coordination was lacking with Fire Spt, Engr. breaching. Good dispersion. Good movement techniques.

Mission -- 15 Mission Statement -- Deliberate Attack

Area of Opns -- Whale

Time Usage Bn at 1/2 instead of 1/3

Co 4/5 met the 1/3 Good rehearsals and Prep.

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	21	1	T72	9	8
M2	18	0	BMP	33	15
M3	5	0	AT-5	6	2
Vul	3	0	BRDM	9	3
Stinger	5	3			

(Centralized ADA control)

Fire Effectiveness	Type	Rds/Kill
	120mm	97
	25mm	180
	TOW	2.9

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	468	0
	Eff	0	0
	Supp	352	0
	Ineff	116	0
	% eff or supp	75%	0%

Air Battle   Red lost 0/6 sorties, Blue lost 6/6 sorties

Summary Notes:

Timing was off on the attack - should have waited. Good massing of fires and combat multipliers. Persistent agent killed many, suspected but no action taken (decision time). Bad movement techniques.

Mission -- 16 Mission Statement -- Deliberate Attack

Area of Opns -- Crash Hill

Time Usage Bn at 1/2 instead of 1/3

Co 2/5 met the 1/3 Prep at 80% to standard.

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	23	3	T72	20	17
M2	28	11	BMP	93	66
M3	10	9	AT-5	9	6
Vul	5	2	BRDM	13	9
Stinger	8	5			

(Centralized ADA control)

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	476	111
Eff	80	0
Supp	108	0
Ineff	288	111
% eff or supp	39%	0%

Air Battle Red lost 12/20 sorties, Blue lost 4/12 sorties

Summary Notes:

The best effort by Engr. Coordination very poor. Arty,

ALO, scouts, all need more TF control. S2 and Cdr need to work together to improve decision loop time. Actions on contact need rehearsal. Task and purpose not well or clearly stated. Focus was on terrain, not enemy.

Mission -- 17 Mission Statement -- Movement to Contact

Area of Opns -- Iron Triangle

Time Usage Bn at 2/9, better than 1/3

Co 1/5 met the 1/3 at 90% to standard - Good

Major Weapons Results

Friendly	Start	Finish
M1	26	1
M2	24	2
M3	3	2
Vul	4	2
Stinger	4	2

(Centralized ADA control)

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	576	0
Eff	24	0
Supp	216	0
Ineff	336	0
% eff or supp	42%	0%

Air Battle Red lost 0/16 sorties, Blue lost 3/8 sorties

Summary Notes:

FA was available but not called much. Mortars not used.

ADA poor early warning. CAS was called but not used once. No event template. Poor agility wrt enemy air. FIST positioning not coordinated. POOR coordination. Bad reporting on FASCAM. 0845 info caused commitment to south. FRAGO was issued. Wrong place at wrong time.

Mission -- 18   Mission Statement -- Defense in Sector

Area of Opns -- Granite Pass

Time Usage Bn at 1/2 instead of 1/3-- Good warning order

Co 2/5 met the 1/3 Prep at 50% to standard-Poor

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	26	6	T72	31	5
M2	25	5	BMP	121	10
M3	3	2	AT-5	15	2
Vul	4	1	BRDM	17	7
Stinger	3	2	(Centralized ADA control)		

Engr Equip	Poss Hrs-Psns		Actual Hrs-Psns	
ACE	84	33	92	48
SEE	63	63	30	14

Engr Standards	Type	Dug	To Standard	Not Used
	Veh	48	20	4
	Crew	14	9	0

Mine Usage   Available - 4818   Used - 4298

Fire Support Effectiveness   Direct-Fire Effectiveness

Category	Arty Rds	Mtr Rds	Type	Rds/Kill

Total	1304	210	120mm	4.8
Eff	568	0	25mm	316
Supp	592	60	TOW	12.6
Ineff	144	150		
% eff or supp	89%	29%		

Air Battle Red lost 3/12 sorties, Blue lost 0/8 sorties

Summary Notes:

1 Fratricide. Good warning order and preparation. Good agility reacting to enemy air assault. Plans were well synchronized Many positions not dug to standard.

Mission -- 19 Mission Statement -- Defense in Sector

Area of Opns -- Hidden Valley/Debnam/Brown

Time Usage Bn at 1/2 instead of 1/3

Co 1/5 met the 1/3 Prep at 75% to standard-Fair/poor

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	20	3	T72	41	22
M2	16	8	BMP	118	44
M3	1	0	AT-5	9	9
Vul	4	1	BRDM	22	16
Stinger	1	1 (Centralized ADA control)			

Engr Equip	Poss Hrs	Poss Psns	Actual Hrs	Actual Psns
ACE	114	38	112	19
SEE	24	24	2	0

Engr Standards	Type	Dug	To Standard	Not Used
	Veh	19	4	0
	Crew	0	0	0

Mine Usage Available - 4800 Used - 2533

Hours Available - 48 Used - 28.5

Fire Support Effectiveness Direct-Fire Effectiveness

Category	Arty Rds	Mtr Rds	Type	Rds/Kill
Total	588	135	120mm	4.4
Eff	0	0	25mm	125
Supp	0	30	TOW	4.7
Ineff	588	105		
% eff or supp	0%	29%		

Air Battle Red lost 4/4 sorties, Blue lost 0/6 sorties

Summary Notes:

Good ADA. Poor agility when receiving scout reports. Tank ditch took hours away from digging positions. Wrong control measures for FA. Poor integration of SITEMP. Ammo repositioning hurt the effort. 50% were not fully stocked. Act quicker on turning points. Fires were not coordinated with the tank ditch.

Mission -- 20   Mission Statement -- Defense in Sector

Area of Opns -- Granite/Tiefort Mt. Approach

Time Usage   Bn   at 1/3, met the standard

Co 2/5 met the 1/3 Prep at 75% to standard-Fair/poor

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	23	4	T72	23	8
M2	24	10	BMP	122	74
M3	4	1	AT-5	9	2
Vul	3	3	BRDM	8	8
Stinger	5	2			

(Centralized ADA control)

Fire Effectiveness	Type	Rds/Kill
	120mm	5
	25mm	263
	TOW	4

Fire Support Effectiveness	Category	Arty Rds	Mtr Rds
	Total	682	100
	Eff	210	0
	Supp	304	30
	Ineff	168	70
	% eff or supp	75%	30%

Air Battle   Red lost 7/10 sorties, Blue lost 4/10 sorties

Summary Notes:

Slow to react to both persistent agent and trigger(S-2). No timeline of critical events. 4 fratricide incidents. Not enough defensive posns. Artillery problems with adjusting and not synchronized during whole battle. Poor agility measure (no refinement of plan). Arty and Air couldn't synchronize.

Mission -- 21 Mission Statement -- Movement to Contact

Area of Opns -- Granite/Tiefort Mt. Approach

Time Usage Bn slightly later than 1/3

Co 3/5 met the 1/3 Prep at 70% to standard-poor

Major Weapons Results

Friendly	Start	Finish	Threat	Start	Finish
M1	25	2	T72	10	3
M2	25	10	BMP	44	15
M3	6	2	AT-5	5	4
Vul	3	2	BRDM	12	8
Stinger	2	2	(Centralized ADA control)		

Fire Support Effectiveness

Category	Arty Rds	Mtr Rds
Total	564	45
Eff	204	0
Supp	264	33
Ineff	96	12
% eff or supp	83%	73%

Air Battle Red lost 4/12 sorties, Blue lost 0/12 sorties

Summary Notes:

Rehearsal took too long. CDR changed plan and B took over A (mech) Mission. Co level control measures not sufficient

(number or detail). Need more combat patience. Agility poor in reacting to enemy actions. Adjusted artillery well. Targets were not used very much, could have hurt synchronization. Good massing of fires. Dispersion poor. S-2 tracking and dissemination needs work. ADA had little coordination. CSS too far behind to give support.

NOTE: The above summaries were accomplished while watching the AARs on a video tape and before any results had been calculated for these battles.

A.3 Digital Databases

The digital data from the most recent battles (those after 1991) are stored in a large database at ARI-POM. The majority of it can be accessed via modem and either queried at Monterey or downloaded and queried at the remote site. ARI-POM has produced several users manuals and has established a qualification course to assist the users in accessing the data and successfully using the system to obtain the desired information. Below is a description of the tables that are automatically created and filled for each battle recorded at the NTC. Only the tables that contain information useful for this research are listed, and only a short explanation is offered as the manuals go into much more detail for each file.

Table A.1: This table lists the status and initial characteristics of all players including the blue force (friendly), the opfor (opposing force) and the administrative players. The ESIT table is used to identify all of the different types of platforms that are used in the particular battle and how many. This information is used in many of the calculations of potential combat power.

Name: ESIT		
Description: Element State Initial Table		
Element Name	**Format**	**Description**
LPN	NUMBER	Logical Player Number
BUNIT	NUMBER	Transmitter ID Number
PLAYER TYPE	CHAR(10)	Type of Element
PID	CHAR(30)	Bumper Number or Unit ID
NHLU	NUMBER	Next Higher Line Unit
NHE	NUMBER	Next Higher Element
NLE	NUMBER	Next Lower Element
SIBLING	NUMBER	Sister Element
INSTRUMENT	CHAR(1)	Instrumented or Not
PL STATUS	CHAR(5)	Position Location Status
RDMS	CHAR(15)	Range Data Measuring System
BATTLE STATUS	CHAR(15)	Status of Element
SIDE	CHAR(1)	Side Element is on
ECHELON	CHAR(10)	Echelon of Element
WEAPON1	NUMBER	Wpn Code #1
FIC 1	NUMBER	Firer Laser's code
WEAPON 2	NUMBER	Wpn Code #2
FIC 2	NUMBER	Firer Laser's code
WEAPON 3	NUMBER	Wpn Code #3
FIC 3	NUMBER	Firer Laser's code
PLATFORM	NUMBER	Type of Vehicle
MOPP LEVEL	CHAR(6)	Level of Chemical Protection
SYMBOL	NUMBER	Display Symbol

Table A.2: This table gives all of the position data (including altitude) for the aircraft involved in the battle. Of course the time is needed along with the identification of the specific aircraft. Fast movers such as an F-15 are included as are attack helicopters (Cobra, Apache).

Name: APLT		
Description: Air Player Location Table		
Element Name	**Format**	**Description**
TIME	CHAR(20)	date/time of location reading
LPN	NUMBER	Logical Player Number
PID	CHAR(8)	Player ID Number
X	NUMBER	UTM x Coordinate
Y	NUMBER	UTM y Coordinate
Z	NUMBER	elevation in feet

Table A.3: This table gives all of the position data (including altitude) for the aircraft involved in the battle. Of course the time is needed along with the identification of the specific aircraft. Fast movers such as an F-15 are included as are attack helicopters (Cobra, Apache).

Table A.4: This table contains the data required for all direct-fire firing events. Direct fire is considered fire that is initiated at the weapons system at an opposing force weapon that can be visually targeted. Any fire from a tank, an armored personnel carrier or from foot soldiers is considered direct-fire for this research.

Name: FET		
Description: Fire Event Table		
Element Name	**Format**	**Description**
TIME	CHAR(20)	date/time of location reading
LPN	NUMBER	Logical Player Number
PID	CHAR(8)	Player ID Number
SIDE	CHAR(1)	Which is the firer on
X	NUMBER	UTM x Coordinate
Y	NUMBER	UTM y Coordinate
WEAPON	NUMBER	Type of Weapon Fired

Table A.5: This table contains the data for indirect-fire missions. An indirect-fire mission is a request for fire (planned or immediate) issued to indirect-fire weapons such as artillery, mortars, naval gunfire, or air support. The mission is issued a number and is fired at a target usually designated by a grid and a target type.

Name: **IFMF**		
Description: Indirect Fire Missions Fired		
Element Name	**Format**	**Description**
TIME	CHAR(20)	date/time of fire mission
LPN	NUMBER	Logical Player Number of Firer
PID	CHAR(8)	Player ID Number of firer
TARGET	CHAR(8)	target name
PLAN ID	CHAR(8)	name of firing plan
SIDE	CHAR(1)	Which is the firer on
BATTERY X	NUMBER	UTM x Coordinate
BATTERY Y	NUMBER	UTM y Coordinate
WEAPON	NUMBER	Type of Weapon Fired
SHELL	CHAR(15)	Type of shell fired
FUSE	CHAR(15)	type of fuse fired
IMPACT X	NUMBER	UTM x Coordinate
IMPACT Y	NUMBER	UTM y Coordinate

Table A.6: This table is the simplest yet most frequently used table in the database. It contains all of the position data for every platform for both sides during the entire battle. GPLT tables are usually very large. sometimes containing more than 30,000 lines. The size of the file depends upon the length of the battle, the time-step chosen for data storage (usually 5 – 20 minutes) and the number of platforms involved in the battle.

Name: GPLT		
Description: Ground Players Location Table		
Element Name	**Format**	**Description**
TIME	CHAR(20)	date/time of location reading
LPN	NUMBER	Logical Player Number
PID	CHAR(8)	Player ID Number
X	NUMBER	UTM x Coordinate
Y	NUMBER	UTM y Coordinate

Appendix B

Operational Lethality Index

As an importance-weighting factor for calculating measures that combine distinct types of weapons systems, the Operational lethality Index (OLI) is used; it appears in the formulas for Maneuver, Combined Arms Balance (and associated sub-concepts), Weapons Usage, Combat Power Projection, Vulnerability, Spatial Control, and Temporal Control. In all these formulas, the OLI value is merely a weighting factor, having the sense that when a measure is an average for several weapons systems, the more lethal systems count more heavily in the average.

Two things should be noted about the OLI: First, although its calculation in terms of other weapon attributes is complicated, for doctrinal conformance measurement purposes it is merely a permanent attribute of a weapons system or of a platform; OLI values for each weapons system can be computed and stored in advance and retrieved when needed. Thus they have no additional effect on parsimony of a doctrinal conformance measure beyond being a weapons-specific parameter in the defining formula for the measure.

Second, the accuracy of OLI values, which is crucial in planning and analysis applications, is irrelevant here. Any reasonable and consistent measure

of relative importance of weapons systems would serve as well as any other. We use OLI because a definite set of numerical definitions exists for it.

Unfortunately, no one has published in the open literature OLI values for the weapons systems used in the present experiments. The formulas are published [Dupuy 85], in terms of weapons attributes that are published in scattered places.

The data in "platform.dat" was the result of OLI calculations. The speed, range, rate of fire, and component weapon systems all had to be researched. A large part of the required information was found in Jane's series of Weapons and Weapons Systems books. Also of use were several current Army field manuals and commercially obtained books on weapon systems.

The Operational Lethality Index (OLI) was calculated using researched characteristics of the platforms and weapon systems used at NTC and the formulas introduced by COL (Ret) Trevor DuPuy. [Dupuy 85] [Dupuy 87] A spreadsheet was useful in performing the computations implied in Dupuy's work.

The tables below contain the both the weapons systems data (Table B.1 through Table B.4) and the platform data (Table B.5 through Table B.10). All of this data was needed to perform the calculations required by Dupuy to finally arrive at an OLI value for each weapon and for each platform.

Table B.1: Friendly Weapon System OLI Calculations (A)

Weapon Name	Weapon Number	Calibre	Rate of Fire	Tgts Per Strike	Relative Effective	Range Factor	Muzzle Velocity	MV Factor
WEAPON UNKOWN	3							
60MM	10	60	180	330	1	2.34	158	0.86
81MM	11	81	156	750	1	3.12	180	1.13
107MM	12	107	126	1300	1	3.45	220	1.59
105MM	20	105	105	1250	1	4.39	500	3.59
155MM	21	155	48	3100	1	4.82	650	5.66
175MM	22	175	40	4600	1	6.72	912	8.45
8INCH	23	207	30	5100	1	5.79	587	5.91
227MM ROCKET	24	227	48	5900	1	6.48	500	5.27
105MM TANK MAIN GUN	30	105	105	1250	1	2.73	650	4.66
120MM TANK MAIN GUN	31	120	92	1800	1	2.87	855	6.56
152MM TANK MAIN GUN	32	152	46	3000	1	2.41	900	7.77
25MM IFV MAIN GUN	40	25	250	80	1	2.58	800	2.80
50CAL MACHINE GUN	50	12.7	2100	2	0.9	2.41	810	2.02
M60 MACHINE GUN	51	7.62	2200	1	0.8	2.34	855	1.65
COAX	52	7.62	2200	1	0.8	1.95	855	1.65
M249 MACHINE GUN	53	5.56	3000	1	0.8	1.89	965	1.59
M16 RIFLE	54	5.56	1700	1	0.6	1.63	921	1.52
40MM GRENADE/M203	55	40	200	180	1	1.59	71	0.31
MARK 19 GRENADE	56	40	1400	180	1	2.26	240	1.06
TOW	60	120	95	1900	1	2.94	120	0.92
DRAGON	61	100	108	1100	1	2.00		0.00
VIPER LAW	62	80	180	750	1	1.71		0.00
SHILLELAGH MISSLE	63	90	180	900	1	2.41		0.00
20MM VULCAN	70	20	3000	3	0.7	2.10	1030	3.22
CHAPARRAL	71	120	4	1900	1	3.00	400	3.07
STINGER	72	70	20	500	1	3.24	348	2.04
30MM AIRBORNE	80	30	2800	10	1	2.73	1050	4.03
20MM AIRBORNE	81	20	3000	8	0.7	3.00	1030	3.22
HELLFIRE	82	200	16	5100	1	3.65		0.00
2.75INCH ROCKET	83	68	140	500	1	3.00	700	4.04
MAVERICKbl of 6	84	200	6	5100	1	5.73		0.00
ROCKEYE	85	100	4	6000	1	1.00	500	3.50

Table B.2: Friendly Weapon System OLI Calculations (B)

Weapon Name	Accuracy	Reliability	Guided Missile	Multiple Charge	Multiple Barrel	Self-Prop Arty Factor	OLI Range	OLI MV	Final OLI
WEAPON UNKOWN									
60MM	0.7	0.9	1	1.05	1	1	23.01	8.42	23.01
81MM	0.6	0.95	1	1.05	1	1	54.64	19.85	54.64
107MM	0.6	0.9	1	1.09	1	1	83.13	38.40	83.13
105MM	0.9	0.95	1	1.12	1	1.1	151.77	123.96	137.86
155MM	0.9	0.95	1	1.15	1	1.1	193.97	227.92	227.92
175MM	0.8	0.8	1	1.15	1	1.05	238.82	300.22	300.22
8INCH	0.95	0.95	1	1.15	1	1.05	241.14	246.43	246.43
227MM ROCKET	0.8	0.9	1	1	3.27	1.1	1,187.63	966.91	1,187.63
105MM TANK MAIN GUN	0.95	0.95	1	1	1	1	80.90	138.07	138.07
120MM TANK MAIN GUN	0.99	0.95	1	1	1	1	111.79	255.28	255.28
152MM TANK MAIN GUN	0.9	0.95	1	1	1	1	71.21	229.11	229.11
25MM IFV MAIN GUN	0.85	0.95	1	1	1	1	10.42	11.31	11.31
50CAL MACHINE GUN	0.8	0.9	1	1	1	1	1.64	1.37	1.51
M60 MACHINE GUN	0.8	0.9	1	1	1	1	0.74	0.52	0.63
COAX	0.8	0.9	1	1	1	1	0.62	0.52	0.57
M249 MACHINE GUN	0.9	0.95	1	1	1	1	0.97	0.82	0.89
M16 RIFLE	0.9	1	1	1	1	1	0.37	0.35	0.36
40MM GRENADE/M203	0.8	1	1	1	1	1	11.46	2.26	6.86
MARK 19 GRENADE	0.8	0.9	1	1	1	1	102.51	48.20	75.35
TOW	0.95	0.9	2	1	1	1	226.55	71.00	226.55
DRAGON	0.95	0.9	1.5	1	1	1	76.18	0.00	76.18
VIPER LAW	0.9	0.95	1	1	1	1	49.26	0.00	49.26
SHILLELAGH MISSLE	0.9	0.95	1.5	1	1	1	125.39	0.00	125.39
20MM VULCAN	0.7	0.95	1	1	1.83	1	4.02	6.18	5.10
CHAPARRAL	0.85	0.9	1.5	1	1	1	6.54	6.69	6.69
STINGER	0.9	0.95	1.5	1	1	1	10.38	6.53	10.38
30MM AIRBORNE	0.9	0.95	1	1	1	1	16.35	24.09	24.09
20MM AIRBORNE	0.6	0.95	1	1	1	1	7.18	7.72	7.72
HELLFIRE	0.99	0.9	1.5	1	1	1	99.41	0.00	99.41
2.75INCH ROCKET	0.7	0.95	1	1	1	1	34.91	47.02	47.02
MAVERICKbl of 6	0.9	0.9	1	1	1	1	35.52	0.00	35.52
ROCKEYE	0.7	0.95	1	1	1	1	3.99	13.97	13.97

Table B.3: OPFOR Weapon System OLI Calculations (A)

Weapon Name	Weapon Number	Calibre	Rate of Fire	Tgts Per Strike	Relative Effective	Range Factor	Muzzle Velocity	MV Factor
120MM	110	120	114	1800	1	3.39	272	2.09
160MM	111	160	58	3700	1	3.83	343	3.04
240MM	112	240	26	6000	1	4.11	400	4.34
122MM HOWITZER	120	122	94	1800	1	4.92	690	5.33
152 HOWITZER	121	152	55	3100	1	4.52	655	5.65
152MM GUN HOWITZER	122	152	55	3100	1	5.17	655	5.65
203MM GUN HOWITZER	123	203	30	5100	1	5.24	580	5.78
122MM ROCKET	124	122	120	1975	1	5.47	450	3.48
220MM ROCKET	125	220	48	5700	1	7.33	500	5.19
FROG-7	126		4	15000	1	9.37		0.00
125MM TANK MAIN GUN	140	125	90	2000	1	2.45	900	7.04
73MM BMP MAIN GUN	150	73	155	550	1	2.14	700	4.19
30MM BMP MAIN GUN	151	30	230	100	1	2.00	1080	4.14
12.7MM MACHINE GUN	160	12.7	2100	2	0.9	2.41	810	2.02
PKT	161	7.62	2600	1	0.8	2.00	855	1.65
AKM	162	7.62	1200	1	0.7	1.55	715	1.38
RPG-7	163	64	240	400	0.8	1.71	80	0.45
AT3-SAGGER	170	120	95	1900	1	2.73	120	0.92
AT4	171	120	95	1900	1	2.41	120	0.92
AT5	172	120	95	1900	1	3.00	120	0.92
AT6	173	120	65	1900	1	3.24	120	0.92
23MM	180	23	1600	50	0.8	2.41	970	3.26
SA9	181	120	4	1900	1	3.83	1879.2	14.41
SA13	182	120	4	1900	1	4.15	1879.2	14.41
SA14	183	120	5	1900	1	3.00	1879.2	14.41
12 7MM AIRBORNE MG	190	12.7	2100	2	0.9	2.41	810	2.02
30MM GUN	191	30	230	100	1	2.00	1080	4.14
57MM ROCKET	192	57	200	280	1	3.00	700	3.70

Table B.4: OPFOR Weapon System OLI Calculations (B)

Weapon Name	Accuracy	Reliability	Guided Missile	Multiple Charge	Multiple Barrel	Self-Prop Arty Factor	OLI Range	OLI MV	Final OLI
120MM	0.7	0.9	1	1.09	1	1	119.32	73.48	119.32
160MM	0.7	0.9	1	1.15	1	1	148.79	118.05	148.79
240MM	0.7	0.9	1	1.15	1	1.05	122.06	128.69	125.37
122MM HOWITZER	0.9	0.9	1	1.15	1	1.05	203.72	220.72	220.72
152 HOWITZER	0.9	0.9	1	1.15	1	1.05	188.48	235.67	235.67
152MM GUN HOWITZER	0.9	0.9	1	1.15	1	1.1	225.85	246.89	246.89
203MM GUN HOWITZER	0.9	0.9	1	1.15	1	1.05	196.15	216.41	216.41
122MM ROCKET	0.6	0.8	1	1	4.18	1.05	682.78	434.30	558.54
220MM ROCKET	0.6	0.8	1	1	3.82	1.05	964.62	683.64	824.13
FROG-7	0.6	0.9	1	1	1	1	75.90	0.00	75.90
125MM TANK MAIN GUN	0.95	0.9	1	1	1	1	94.23	271.00	271.00
73MM BMP MAIN GUN	0.75	0.95	1	1	1	1	32.50	63.57	63.57
30MM BMP MAIN GUN	0.95	0.95	1	1	1	1	10.38	21.49	21.49
12.7MM MACHINE GUN	0.7	0.9	1	1	1	1	1.44	1.20	1.32
PKT	0.9	1	1	1	1	1	0.94	0.77	0.85
AKM	0.9	1	1	1	1	1	0.29	0.26	0.28
RPG-7	0.85	1	1	1	1	1	27.86	7.31	17.58
AT3-SAGGER	0.6	0.7	2	1	1	1	103.56	34.88	103.56
AT4	0.6	0.7	2	1	1	1	91.50	34.88	91.50
AT5	0.6	0.7	2	1	1	1	113.72	34.88	113.72
AT6	0.7	0.7	2	1	1	1	97.91	27.84	97.91
23MM	0.8	0.9	1	1	1	1	27.81	37.51	37.51
SA9	0.8	0.95	1.5	1	1	1	8.29	31.21	31.21
SA13	0.8	0.95	1.5	1	1	1	8.99	31.21	31.21
SA14	0.8	0.95	1.5	1	1	1	8.12	39.01	39.01
12 7MM AIRBORNE MG	0.7	0.9	1	1	1	1	1.44	1.20	1.32
30MM GUN	0.95	0.95	1	1	1	1	10.38	21.49	21.49
57MM ROCKET	0.7	0.95	1	1	1	1	27.93	34.44	34.44

Table B.5: Friendly Platform OLI Calculations (A)

Platforms w/ Weapon Systems	Platform Number	Speed Km/Hr	Range w/ Gas	Weight (tons)	Weapon #1	Weapon #2	Weapon #3	Composite OLI's
UNDEF_PLATFORM	1							
M60_TANK	30	48.28	500	52.60	138.07	125.39	1.51	264.21
M1_TANK	31	72.4	498	54.50	138.07	0.57	1.51	139.39
M1A1_TANK	32	66.8	465	57.00	255.28	0.57	1.51	256.60
M551_TANK	33	70	600	15.80	229.11	0.57	1.51	230.44
M2_IFV	40	66	483	22.50	11.31	226.55	0.57	290.46
M3_CFV	41	66	483	22.40	11.31	226.55	0.57	290.46
M113_APC	42	64	483	12.00	1.51	0.00	0.00	1.51
M113_WITH_TOW	43	64	483	12.00	226.55	0.57	0.00	227.12
M901_AT_APC	44	64	483	12.00	226.55	0.57	0.00	227.12
SP_VULCAN M163	50	64	483	12.00	5.10	0.57	0.00	5.67
MANPACK_STINGER	51	6	0	0.00	24.09	0.00	0.00	24.09
SP_CHAPPARAL-M548	52	64	475	10.00	6.69	1.51	0.00	8.20
MANPACK_M16	60	6		0.00	0.36	0.00	0.00	0.36
MANPACK_M16	61	6		0.00	0.36	0.00	0.00	0.36
MANPACK_M60	62	6		0.00	0.63	0.00	0.00	0.63
MANPACK_M249	63	6		0.00	0.89	0.00	0.00	0.89
MANPACK_M203	64	6		0.00	6.86	0.00	0.00	6.86
MANPACK_TOW	65	6		0.00	226.55	0.00	0.00	226.55
MANPACK_DRAGON	66	6		0.00	76.18	0.00	0.00	76.18
MANPACK_VIPER_LAW	67	6		0.00	49.26	0.00	0.00	49.26
MANPACK_MARK_19	68	6		0.00	75.35	0.00	0.00	75.35
FIST_V	80	64	483	12.00	1.51	0.57	0.00	2.08
M224_MORTAR	85	64	483	12.00	23.01	0.00	0.00	23.01
M125_SP_MORTAR	90	64	483	12.00	54.64	1.51	0.00	56.15
M106_SP_MORTAR	91	64	483	12.00	83.13	1.51	0.00	84.64
M108_SP_HOWITZER	100	54.7	523	22.40	137.86	0.00	0.00	137.86
M109_SP_HOWITZER	101	56.3	349	25.00	227.92	0.00	0.00	227.92
M107_SP_GUN_HOWITZER	102	56	725	28.20	300.22	0.00	0.00	300.22
M110_SP_HOWITZER	103	54.7	523	28.00	246.43	0.00	0.00	246.43
MLRS	104	64	483	25.00	1,187.63	0.00	0.00	1,187.63
AH_64	110	276	480	6.00	99.41	24.09	47.02	147.01
AH_1S	111	276	506	4.50	226.55	24.09	47.02	274.16
OH_58	112	220.8	480	1.40	0.86	0.00	0.00	0.86
UH_1	113	203.2	508.8	1.30	0.95	0.00	0.00	0.95
UH_60	114	294.4		9.32	99.41	0.00	0.00	99.41
A10	120	708.8	460.8	21.55	63.85	35.52	0.00	99.37
FIGHTER	121					0.00	0.00	0.00
BOMBER	122					0.00	0.00	0.00
FIGHTER_BOMBER	123					0.00	0.00	0.00

Table B.6: Friendly Platform OLI Calculations (B)

Platforms w/ Weapon Systems	Mobility Factor	Radius Factor	Punish Factor	Raw OLI	Rapidity Of Fire	Fire Cntl
UNDEF_PLATFORM						
M60_TANK	1.04	1.79	134.88	627.48	0.93	0.9
M1_TANK	1.28	1.79	213.37	530.99	0.93	1.1
M1A1_TANK	1.23	1.73	228.22	770.92	0.92	1.1
M551_TANK	1.25	1.96	22.20	588.91	0.8	0.8
M2_IFV	1.22	1.76	56.60	678.93	1	1
M3_CFV	1.22	1.76	56.22	678.55	1	1
M113_APC	1.20	1.76	14.70	17.88	1	1
M113_WITH_TOW	1.20	1.76	14.70	493.89	0.92	1
M901_AT_APC	1.20	1.76	7.35	486.54	0.92	1
SP_VULCAN M163	1.20	1.76	14.70	26.66	1	1
MANPACK_STINGER	1.00	1.00	0.00	24.09	1	1
SP_CHAPPARAL-M548	1.20	1.74	11.18	28.33	1	1
MANPACK_M16	1.00	1.00	0.00	0.36	1	1
MANPACK_M16	1.00	1.00	0.00	0.36	1	1
MANPACK_M60	1.00	1.00	0.00	0.63	1	1
MANPACK_M249	1.00	1.00	0.00	0.89	1	1
MANPACK_M203	1.00	1.00	0.00	6.86	1	1
MANPACK_TOW	1.00	1.00	0.00	226.55	1	1
MANPACK_DRAGON	1.00	1.00	0.00	76.18	1	1
MANPACK_VIPER_LAW	1.00	1.00	0.00	49.26	1	1
MANPACK_MARK_19	1.00	1.00	0.00	75.35	1	1
FIST_V	1.20	1.76	14.70	19.08	1	1
M224_MORTAR	1.20	1.76	14.70	63.24	1	1
M125_SP_MORTAR	1.20	1.76	14.70	133.15	1	1
M106_SP_MORTAR	1.20	1.76	14.70	193.27	1	1
M108_SP_HOWITZER	1.11	1.83	0.00	279.82	1	1
M109_SP_HOWITZER	1.13	1.49	0.00	383.38	1	1
M107_SP_GUN_HOWITZER	1.12	2.15	0.00	725.91	1	1
M110_SP_HOWITZER	1.11	1.83	0.00	500.16	1	1
MLRS	1.20	1.76	0.00	2,505.68	1	1
AH_64	2.49	1.75	2.60	395.86	1	1
AH_1S	2.49	1.80	1.69	752.65	1	1
OH_58	2.23	1.75	0.29	2.25	1	1
UH_1	2.14	1.80	0.26	2.44	1	1
UH_60	2.57	0.00	5.03	52.22	1	1
A10	3.99	1.72	17.68	699.18	1	1
FIGHTER	0.00	0.00	0.00	0.00	1	1
BOMBER	0.00	0.00	0.00	0.00	1	1
FIGHTER_BOMBER	0.00	0.00	0.00	0.00	1	1

Table B.7: Friendly Platform OLI Calculations (C)

Platforms w/ Weapon Systems	Basic Load	Ammo Supply	Ceiling	Amphib Effect	Wheels or Halftrack	Refined OLI
UNDEF_PLATFORM						
M60_TANK	63	0.93	1	1.05	1	512.86
M1_TANK	55	0.9	1	1.05	1	513.33
M1A1_TANK	40	0.87	1	1.05	1	712.69
M551_TANK	30	0.94	1	1.1	1	389.72
M2_IFV	900	1	1	1.1	1	746.82
M3_CFV	1500	1	1	1.1	1	746.41
M113_APC	2000	1	1	1.1	1	19.67
M113_WITH_TOW	12	0.39	1	1.1	1	194.93
M901_AT_APC	12	0.39	1	1.1	1	192.03
SP_VULCAN M163	3400	1	1	1.1	1	29.32
MANPACK_STINGER	4	0.6	1	1	1	14.46
SP_CHAPPARAL-M548	12	1	1	1.1	1	31.16
MANPACK_M16	1	1	1	1	1	0.36
MANPACK_M16	1	1	1	1	1	0.36
MANPACK_M60	1	1	1	1	1	0.63
MANPACK_M249	1	1	1	1	1	0.89
MANPACK_M203	1	1	1	1	1	6.86
MANPACK_TOW	1	1	1	1	1	226.55
MANPACK_DRAGON	1	1	1	1	1	76.18
MANPACK_VIPER_LAW	1	1	1	1	1	49.26
MANPACK_MARK_19	1	1	1	1	1	75.35
FIST_V	500	0.74	1	1	1	14.12
M224_MORTAR	1	1	1	1.1	1	69.56
M125_SP_MORTAR	114	1	1	1.1	1	146.47
M106_SP_MORTAR	93	1	1	1.1	1	212.60
M108_SP_HOWITZER	1	1	1	1.05	1	293.81
M109_SP_HOWITZER	1	1	1	1.05	1	402.54
M107_SP_GUN_HOWITZER	1	1	1	1.05	1	762.20
M110_SP_HOWITZER.	1	1	1	1.05	1	525.17
MLRS	1	1	1	1.05	1	2,630.96
AH_64	1	1	0.6	1	1	237.52
AH_1S	1	1	0.6	1	1	451.59
OH_58	1	1	0.6	1	1	1.35
UH_1	1	1	0.6	1	1	1.46
UH_60	1	1	0.6	1	1	31.33
A10	1	1	0.9	1	1	629.27
FIGHTER	1	1	1	1	1	1,296.00
BOMBER	1	1	1	1	1	810.00
FIGHTER_BOMBER	1	1	1	1	1	950.00

Table B.8: Enemy Platform OLI Calculations (A)

Platforms w/ Weapon Systems	Platform Number	Speed Km/Hr	Range w/ Gas	Weight (tons)	Weapon #1	Weapon #2	Weapon #3	Composite OLI's
T72_TANK	160	80	480	41.50	271.00	0.85	1.32	272.52
BMP1	170	80	500	13.70	63.57	0.85	113.72	142.81
BMP2	171	65	550	14.30	21.49	0.85	113.72	100.16
BMP	172	80	500	13.00	63.57	0.85	1.32	86.05
BRDM	173	100	750	5.60	1.32	0.85	0.00	2.17
BRDM2_AT5	174	100	750	7.00	113.72	0.00	0.00	113.72
BRDM_AT3	175	100	750	7.00	103.56	0.00	0.00	103.56
ZSU-23-4	180	44	260	8.00	37.51	0.00	0.00	37.51
BRDM2_AD	181	100	750	7.00	31.21	17.58		48.80
MTLB w SA-13	182	61.5	500	11.90	31.21	0.85		32.07
MANPACK_SA14	183	6		0.00	39.01	0.00		39.01
MANPACK	190	6		0.00	0.00	0.00		0.00
MANPACK_AKM	191	6		0.00	0.28	0.00		0.28
MANPACK_PKT	192	6		0.00	0.85	0.00		0.85
MANPACK_AT3	193	6		0.00	103.56	0.00		103.56
MANPACK_AT4	194	6		0.00	91.50	0.00		91.50
MANPACK_RPG	195	6		0.00	17.58	0.00		17.58
M1943_MORTAR	200	80	500	13.00	119.32	0.00		119.32
M160_MORTAR	201	80	500	13.00	148.79	0.00		148.79
M240_MORTAR	202	80	500	13.00	125.37	0.00		125.37
122_SP_HOWITZER	210	80	600	15.70	220.72	0.00		220.72
152_SP_HOWITZER	211	50	500	42.00	235.67	0.00		235.67
152_SP_GUN_HOWITZER	212	62	500	30.00	246.89	0.00		246.89
203_SP_GUN_HOWITZER	213	50	500	40.00	216.41	0.00		216.41
BM21_MRL	214	75	405		558.54	0.00		558.54
BM27_MRL	215	65	500		824.13	0.00		824.13
FROG - 7	216	65	500		75.90	0.00		75.90
HIND_D	220	310	160	11.00	215.40	56.27	2.75	68.26
HIND_E	221	310	160	11.00	215.40	146.87	2.75	90.91
UH_HIP	222	240	307	12.00	215.40	1.32	34.44	58.48
OH_HOPLITE	223	240	307	12.00	2.745758	56.27	0.00	14.75
FIGHTER	230					0.00		0.00
BOMBER	231					0.00		0.00
FIGHTER_BOMBER	232					0.00		0.00

Table B.9: Enemy Platform OLI Calculations (B)

Platforms w/ Weapon Systems	Mobility Factor	Radius Factor	Punish Factor	Raw OLI	Rapidity Of Fire	Fire Cntl
T72_TANK	1.34	1.75	94.52	735.35	0.9	1
BMP1	1.34	1.79	17.93	360.66	1	1
BMP2	1.21	1.88	19.12	246.37	1	1
BMP	1.34	1.79	16.57	223.09	1	1
BRDM	1.50	2.19	2.34	9.49	1	0.9
BRDM2_AT5	1.50	2.19	3.27	376.98	0.99	0.9
BRDM_AT3	1.50	2.19	3.27	343.60	1	0.9
ZSU-23-4	0.99	1.29	8.00	56.15	1	0.9
BRDM2_AD	1.50	2.19	6.55	166.91	1	0.9
MTLB w SA-13	1.18	1.79	14.51	81.99	1	0.9
MANPACK_SA14	1.00	1.00	0.00	39.01	1	1
MANPACK	1.00	1.00	0.00	0.00	1	1
MANPACK_AKM	1.00	1.00	0.00	0.28	1	1
MANPACK_PKT	1.00	1.00	0.00	0.85	1	1
MANPACK_AT3	1.00	1.00	0.00	103.56	1	1
MANPACK_AT4	1.00	1.00	0.00	91.50	1	1
MANPACK_RPG	1.00	1.00	0.00	17.58	1	1
M1943_MORTAR	1.34	1.79	0.00	286.36	1	1
M160_MORTAR	1.34	1.79	0.00	357.10	1	1
M240_MORTAR	1.34	1.79	0.00	300.90	1	1
122_SP_HOWITZER	1.34	1.96	0.00	580.29	1	1
152_SP_HOWITZER	1.06	1.79	0.00	447.15	1	1
152_SP_GUN_HOWITZER	1.18	1.79	0.00	521.63	1	1
203_SP_GUN_HOWITZER	1.06	1.79	0.00	410.61	1	1
BM21_MRL	1.30	1.61	0.00	1,168.14	1	1
BM27_MRL	1.21	1.79	0.00	1,782.87	1	1
FROG - 7	1.21	1.79	0.00	164.19	1	1
HIND_D	2.64	1.01	6.45	128.57	1	1
HIND_E	2.64	1.01	6.45	170.16	1	1
UH_HIP	2.32	1.40	7.35	128.17	1	1
OH_HOPLITE	2.32	1.40	7.35	35.08	1	1
FIGHTER	0.00	0.00	0.00	0.00	1	1
BOMBER	0.00	0.00	0.00	0.00	1	1
FIGHTER_BOMBER	0.00	0.00	0.00	0.00	1	1

Table B.10: Enemy Platform OLI Calculations (C)

Platforms w/ Weapon Systems	Basic Load	Ammo Supply	Ceiling	Amphib Effect	Wheels or Halftrack	Refined OLI
T72_TANK	45	0.9	1	1.05	1	625.41
BMP1	40	1	1	1.1	1	396.73
BMP2	500	1	1	1.1	1	271.01
BMP	40	1	1	1.1	1	245.40
BRDM	500	0.75	1	1.1	0.9	6.34
BRDM2_AT5	15	0.9	1	1.1	0.9	299.28
BRDM_AT3	14	0.84	1	1.1	0.9	257.16
ZSU-23-4	2000	1	1	1.1	0.9	50.03
BRDM2_AD	4	1	1	1.1	0.9	148.72
MTLB w SA-13	4	1	1	1.1	1	81.17
MANPACK_SA14		1	1	1	1	39.01
MANPACK		1	1	1	1	0.00
MANPACK_AKM		1	1	1	1	0.28
MANPACK_PKT		1	1	1	1	0.85
MANPACK_AT3		1	1	1	1	103.56
MANPACK_AT4		1	1	1	1	91.50
MANPACK_RPG		1	1	1	1	17.58
M1943_MORTAR		1	1	1	1	286.36
M160_MORTAR		1	1	1.1	1	392.81
M240_MORTAR		1	1	1.1	1	330.99
122_SP_HOWITZER		1	1	1.1	1	638.31
152_SP_HOWITZER		1	1	1.1	1	491.86
152_SP_GUN_HOWITZER		1	1	1.1	1	573.79
203_SP_GUN_HOWITZER		1	1	1.1	1	451.67
BM21_MRL	40 barrels	1	1	1	0.9	1,051.32
BM27_MRL	16 barrels	1	1	1	0.9	1,604.59
FROG - 7	1	1	1	1	1	164.19
HIND_D		1	0.6	1	1	77.14
HIND_E		1	0.6	1	1	102.10
UH_HIP		1	0.6	1	1	76.90
OH_HOPLITE		1	0.6	1	1	21.05
FIGHTER		1	1	1	1	1,296.00
BOMBER		1	1	1	1	810.00
FIGHTER_BOMBER		1	1	1	1	950.00

Appendix C

FORTRAN Programs

C.1 Maneuver

The following program was written to be compiled and run by a FORTRAN 77 compiler. The program name is: "man.f". It prints its output in a file named "man.dat". The rest of the particulars are contained within the documentation of the the program itself.

```
      Program Maneuver_Measure


c
c     Find the relative maneuver characteristic by measuring
c     the distance and time of the movement of each weapon
c     system compared against its maximum possible speed.
c
      integer platfm
      real gpnum(30000,6),lpn,oli,range,speed,measure,toli,
     +tottime,totdist,sum
      character*20 time,gptime(30000)
```

```
      character*1 side
      open(unit=6,file='data/gplt.ntc',status='old')
      open(unit=7,file='data/battle.dat',status='old')
      open(unit=8,file='man.dat',status='unknown')
c
c     Initiate the counter, the sum of the maneuver
c     calculations and the total OLI (toli) at zero.
c
      i=0
      toli=0
      sum=0
c     The i counter is incremented and the gplt.ntc file
c     is read.
c     gptime(i) - time of reading
c     gpnum(i,1)- Logicial Player Number (LPN)
c     gpnum(i,2)- the x coordinate of the player
c     gpnum(i,3)- the y coordinate of the player
c
 20   i=i+1
      read(6,11,end=30)gptime(I),gpnum(I,1),gpnum(I,2)
     +,gpnum(I,3)
 11   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
      goto20
c
c     Read in the info from battle.dat
c
```

```
 30   close(unit=6)
      j=1
c
c     Read in the info from battle.dat-locally produced
c     file showing characteristics of each player
c     depending upon the platform and the weapons.
c     lpn         - Logical Player Number
c     platfm      - Platform number
c     side        - indicates the side of the player
c                B  - Blue or friendly side
c                O  - Opposing force or enemy side
c                T,L,A - administrative, no effect on the
c                        battle
c     oli         - Operational Lethality Index OLI, from
c                Trevor DuPuy's work with the QJM model.
c     speed       - speed of platform, not used in this
c                   program
c     range       - Range factor(as proposed by Trevor
c                   DuPuy
c               = 1 + sqrt(range (KM)) of the most important
c                   wpn on that platform
c
 35   read(7,*,end=1000)lpn,platfm,side,oli,speed,range
c
c     If the record is of the opposing force or if the OLI
c     is zero then we don't want to look at it so we go
```

```
c     to the next record.
c
      if(side.ne.'B'.OR.oli.eq.0.0)goto 35
c
c     Initialize the total distance and total time to be
c     summed as the calculations occur.
c
      totdist=0.0
      tottime=0.0
      do 200 j=1,i-1
c
c     Check for a match with the LPN (logical player
c     number) if no match then look at the next record
c     in battle.dat
c
         if(gpnum(j,1).eq.lpn)then
            x0=gpnum(j,2)
            y0=gpnum(j,3)
            time=gptime(j)
            do 300 jj=j,i-1
c
c     Here we check for the next occurrence of the LPN
c     established by the record number from gplt.ntc and
c     matched to its first occurrence in battle.dat.
c     Its grid (gpnum(jj,2),gpnum(jj,3) is then used to
c     determine the distance traveled during the elapsed
```

```
c     time.
c
                if(gpnum(jj,1).ne.lpn)goto 300
c
c Classical distance formula dist=sqrt[(x-x0)^2+y-y0)^2]
c
                dist=sqrt((gpnum(jj,2)-x0)**2+(gpnum(jj,3)
     +-y0)**2)
                if(dist.le.5)goto 300
c
c     Keep a running total of the distance traveled by
c     this asset. Since each time period is always 5
c     minutes from the last one, add 5 minutes to the
c     total time.
c
                totdist=totdist+dist
                tottime=tottime+5.0
                x0=gpnum(jj,2)
                y0=gpnum(jj,3)
 300         continue
             if(tottime.eq.0.0)goto 35
c
c     Here we sum the weighted speed (weighted by OLI
c     for that asset and normalized by the maximum
c     speed for that asset.
c
```

```
              sum=sum+(oli/speed)*(totdist/tottime)*
     +(60.0/1000.0)
              toli=toli+oli
              goto 30
           endif
200   continue
      goto 35
1000 measure=sum/toli
      write(8,1010)measure
1010 format('The overall measure of maneuver for the
     +battle is ',f10.4)
      end
```

Combined Arms Two different programs were used to calculate the combined arms measure. The first program is called "carm.f" and is found below. Its results are printed into a file called "carm.dat".

```
      Program Combined_Arms_Man_and_FS
c
c     This prgram will take the data from volume.dat
c     and wpnct.dat and calculate what percentage of
c     possible usage was actually implemented.
c
integer wpn,iw,iw2
real rds(100),nw(100),rof(100),oli(100),
     +manmax,manact,fsmax,fsact,fsscore,manscore
      open(unit=6,file='data/volume.dat',
     +status='old')
      open(unit=7,file='data/wpnct.dat',
     +status='old')
      open(unit=8,file='data/wpnoli.dat',
     +status='old')
      open(unit=10,file='carm.dat',
     +status='unknown')
      manmax=0.0
      manact=0.0
      fsmax=0.0
      fsact=0.0
      do 1000 iw=10,85
```

```
      close(unit=6)
      close(unit=7)
      close(unit=8)
      open(unit=6,file='data/volume.dat',
     +status='old')
      open(unit=7,file='data/wpnct.dat',
     +status='old')
      open(unit=8,file='data/wpnoli.dat',
     +status='old')
 100  read(7,*,end=1000)wpn,nw(iw)
c
c     Read in the number of weapons involved in the
c     battle for weapon type.  This will allow
c     calculation of the maximum number rounds that
c     could theoretically be fired in the battle
c
      if(wpn.ne.iw)goto 100
 200  read(6,*,end=1000)wpn,rds(iw)
c
c     Read in the rounds that were (actually) fired
c     during the battle for each wepon type.
c
      if(wpn.ne.iw)goto 200
 300  read(8,*,end=1000)wpn,rof(iw),oli(iw)
c
c     Read in the rate of fire (rof(iw)) and the
```

```
c     OLI (oli(iw)) for the weapon type that was
c     orignally produced by the spreadsheet that
c     calculated Dupuy's OLI
c
         if(wpn.ne.iw)goto 300
 1000 continue
      do 2000 iw2=10,85
         close(unit=9)
      open(unit=9,file='data/ifmf.ntc',status='old')
c
c     These if statements identify the type of
c     weapon (ie maneuver, fire support, ada, etc.)
c     Since this program only works with maneuver and
c     Fire Support, the rest are ignored.
c
         if(iw2.le.32.AND.iw2.ge.30)goto 1500
         if(iw2.eq.40)goto 1500
         if(iw2.le.56.AND.iw2.ge.50)goto 1500
         if(iw2.le.63.AND.iw2.ge.60)goto 1500
c
c     The group of statements identify the maneuver
c     weapon types
c
         if(iw2.le.12.AND.iw2.ge.10)then
            tubes=6
            goto 1100
```

```
           endif
        if(iw2.le.24.AND.iw2.ge.20)then
           tubes=8
           if(iw2.eq.24)tubes=12
           goto 1100
           endif
        if(iw2.le.85.AND.iw2.ge.80)then
           tubes=1
           goto 1100
           endif
c
c     If the weapon type is not maneuver or FS, go
c     get another weapon type number.
c
        goto 2000
c
c     The second set identifies the fire support
c     (including Air)
c
 1100   read(9,15,end=1200)wpn
 15     format(107x,i6)
c
c     This is an extra step for the fire support
c     weapons since the fet.ntc table does not
c     contain these weapons.  One must enter the
c     ifmf.ntc table to find out which missions
```

```
c      were fired and then to add up the missions
c      for each weapon system.  Also, because
c      ifmf.ntc does not contain the number of
c      rounds fired for each mission, it assumed
c      that the number listed for 'tubes' is the
c      number of rounds actually called for.
c      This number is simply the number of tubes
c      typically firing at one target:
c      battery for artillery
c      platoon for mortars
c      two pods for MLRS
c      one bomb for Aircraft
c      The number may be changed based upon the
c      SOP of the unit or a change in TOE .
c
         if(wpn.eq.iw2)rds(iw2)=rds(iw2)+tubes
         goto 1100
c
c      Fire Support maximum and actual usage
c      numbers are calculated
c
 1200    fsmax=fsmax+oli(iw2)*nw(iw2)
         write(10,*)iw2,fsmax,nw(iw2)
         fsact=fsact+(oli(iw2)/rof(iw2))*
     +rds(iw2)
         goto 2000
```

```
c
c     Maneuver maximum and actual usage numbers
c     are calculated
c
 1500     manmax=manmax+oli(iw2)*nw(iw2)
          manact=manact+(oli(iw2)/rof(iw2))*
    +rds(iw2)
 2000 continue
      write(10,20)manmax,manact
 20   format('The maneuver max is',e13.4,'The
    +actual usage was',e13.4)
      manscore=manact/manmax
      write(10,21)manscore
 21   format('The maneuver weapons usage score is '
    +,e13.4)
      write(10,22)fsmax,fsact
 22   format('The Fire Spt max is',e13.4,'The actual
    +usage was',e13.4)
      fsscore=fsact/fsmax
      write(10,23)fsscore
 23   format('The Fire Spt weapons usage score is '
    +,e13.4)
      end
```

Air Defense The next program for the combined arms measure is called "ada.f". Its results are printed in the file called "ada.dat". The air defense portion of the combined arms measure is based upon proper coverage of the friendly forces by air defense assets rather than on the actual firing of air defense weapons. Therefore, the coverage had to be computed for each time period and subsequently averaged.

```
      Program ADA_CA_Measure

c
c     Find the percentage of friendly assets that
c     are, by current tactical standards, adequately
c     covered by Brigade or lower ADA assets.  The
c     rule of thumb in manuals is to have an asset
c     within 1/3 of the effective range of the ADA
c     weapon to be adequately covered.
c
      integer jtime,covrd(2000)
      real speed,gpnum(2000,6),lpn,range(100),adax,
     +aday,dist,covoli,percent,froli(100),adaoli
      character*20 timex,gptime(2000),gpside(2000)
      open(unit=6,file='data/gplt.ntc',status='old')
      open(unit=7,file='data/battle.dat',
     +status='old')
      open(unit=8,file='ada.dat',status='unknown')
```

```
      jtime=1
      adaoli=0.0
      avg=0.0
      read(6,10)timex
 10   format(a20)
      close(unit=6)
      open(unit=6,file='data/gplt.ntc',
     +status='old')
 20   close(unit=7)
      open(unit=7,file='data/battle.dat',
     +status='old')
      i=i+1
      read(6,11,end=1000)gptime(I),gpnum(I,1),
     +gpnum(I,2),gpnum(I,3)
 11   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
c
c     ''covrd(i)'' indicated that wpn system (i)
c     has not yet been identified as being within
c     the umbrella of the ADA assets.
c
      covrd(i)=0
      if(gptime(I).ne.timex)then
         timex=gptime(I)
         num1=gpnum(I,1)
         num2=gpnum(I,2)
         num3=gpnum(I,3)
```

```
         goto 40
      endif
c
c     Read in the information from battle.dat
c
 105  read(7,*,end=20)lpn,gpnum(i,6),
     +gpside(i),gpnum(i,4),speed,gpnum(i,5)
      if(lpn.ne.gpnum(i,1))goto 105
      goto 20
 40   ncount=i-1
c
c     Identify the three ADA battalion level
c     weapon types and platform numbers.
c
c      vulcan=50
c      stinger=51
c      chapparal=52
c
c     Establish their ranges -- could be
c     looked up in  battle.dat
c     Below are the range FACTORS
c
      range(50)=1200.0
      range(51)=5000.0
      range(52)=4000.0
      do 150 i=1,ncount
```

```
c
c    Check for Blue or Opfor weapon system
c
         if(gpside(i).eq.'B')then
c
c    If it is not friendly (Blue) then we are
c    not interested. If it is friendly, add
c    the OLI to the total OLI for this time
c    period
c
            froli(jtime)=froli(jtime)+gpnum(i,4)
            if(gpnum(i,1).eq.50.OR.gpnum(i,1)
     +.eq.51.OR.
     +gpnum(i,1).eq.52)adaoli=adaoli+gpnum(i,4)
c
c    If the friendly asset is also an ada asset,
c    then add it to the total ada OLI for the
c    period.
c
         endif
 150  continue
      do 200 i=50,52
c
c    For only the ada weapon systems
c    Do the following:
c
```

```
      do 300 isys=1,ncount
         if(gpnum(isys,6).eq.i)then
            adax=gpnum(isys,2)
            aday=gpnum(isys,3)
c
c     Here we are keeping track of the location
c     of the ada assets
c
            do 400 jsys=1,ncount
c
c      Check for asset being on right side and
c      being within range of the ADA asset.
c
            if(gpside(jsys).ne.'B'.OR.
     +covrd(jsys).eq.1) goto 400
            dist=sqrt((adax-gpnum(jsys,2))**2
     ++(aday-gpnum(jsys,3))**2)
               if(dist.le.(range(i)/3.0))then
c
c      Covoli represents the total oli adequately
c      covered by at least one of the ADA assets.
c
                  covrd(jsys)=1
                  covoli=covoli+gpnum(jsys,4)
               endif
 400        continue
```

```
          endif
 300      continue
 200   continue
       percent=covoli/froli(jtime)
       write(8,110)covoli,froli(jtime),percent
 110   format(2x,'ADA assets covered ',f13.2)
       write(8,111)froli(jtime),percent
 111   format('Total Friendly OLI=',f13.2,'Perc
      +Covered=',
      +f8.5)
c
c      Reset all counters for a time period,
c      advance the time period counter, and keep
c      a running total (average) of the percent
c      covered.
c
       jtime=jtime+1
       avg=avg+percent
       covoli=0.0
       i=1
       covrd(i)=0
       froli(jtime)=0.0
       gpnum(i,1)=num1
       gpnum(i,2)=num2
       gpnum(i,3)=num3
       goto 105
```

```
 1000 adaoli=adaoli/float(jtime)
      avg=avg/float(jtime)
c
c     Here we are simply printing out the
c     average percent of friendly assets covered
c     by at least one of the ada assets.
c
      write(8,1001)avg,adaoli
 1001 format('ADA score=',e13.4,'ADA OLI=',e13.4)
      end
```

Control There were two programs written for the measure of control. The first deals with spatial control and is called "sc.f". Its results are printed into a file called "sc.dat".

```
      Program Spatial_Control_Analysis
c
c     This program will calculate the spatial
c     control for each time period and then average
c     the calculations to get. a measure.  First,
c     the grid that will be examined will be
c     determined by looking at the min and max X and
c     Y coords for the time period.  Then a margin
c     will be added to both ends to define the
c     entire region of conern.
c
      real x,y,xmin,ymin,xmax,ymax,lpn,toli(100),
     +score
      real speed,gpnum(35000,7),gridden,centerx,
     +centery,delta2
      integer platfm,idelta,ncount(100),ylow,xleft
      character*20 timex,gptime(35000),gpside(35000)
      open(unit=6,file='data/gplt.ntc',status='old')
      open(unit=7,file='data/battle.dat',
     +status='old')
      open(unit=8,file='sc.dat',status='unknown')
c
```

```
c     The unit grid square is set at(idelta X idelta)
c     The size of the grid squares (idelta), the
c     final score (score),the record counter(i), a
c     utility counter(ict), and the time period
c     counter which is the number of 5 minute time
c     periods in the battle, (nperiod).
c
      idelta=2000
      delta2=float(idelta)/2.00
      pi=4.0d+00*atan(1.0d+00)
      i=0
      j=0
      nperiod=0
      ict=0
      write(8,1)
 1    format('Min Entropy     Act Entropy    Max
     +Entropy       Score')
c
c
c     Find the first time (timex) and then close
c     the file (gplt.ntc) again.  This time is
c     used as a time period separator or sorter.
c
      read(6,10)timex,lpn,x,y
 10   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
      close(unit=6)
```

```
      open(unit=6,file='data/gplt.ntc',
     +status='old')
c
c
c     The first loop atarts with 90.  The period
c     counter is incremented and the min and max
c     grid coordinates are initialized with the x
c     and y coordinates of the first record.
c     These man and max coords are dimensioned so
c     that they can be used as search limiters
c     when setting up the do loops for aggregating
c     the combat power in each grid. toli(nperiod)
c     is the total OLI during a given time period.
c
 90   nperiod=nperiod+1
      toli(nperiod)=0.0
      xmax=x
      xmin=x
      ymax=y
      ymin=y
 100  close(unit=7)
      open(unit=7,file='data/battle.dat',
     +status='old')
c
c     The i counter is incremented and the gplt.ntc
c     file is read.
```

```
c      gptime(i) - time of reading
c      gpnum(i,1)- Logicial Player Number (LPN)
c      gpnum(i,2)- the x coordinate of the player
c      gpnum(i,3)- the y coordinate of the player
c
       i=i+1
       read(6,10,end=250)gptime(I),gpnum(I,1),
      +gpnum(I,2),+gpnum(I,3)
c
c      Establish the boundaries of the region being
c      evaluated
c
       if(gpnum(I,2).lt.xmin)xmin=gpnum(I,2)
       if(gpnum(I,2).gt.xmax)xmax=gpnum(I,2)
       if(gpnum(I,3).lt.ymin)ymin=gpnum(I,3)
       if(gpnum(I,3).gt.ymax)ymax=gpnum(I,3)
c
c      Read in the info from battle.dat-locally
c      produced file showing characteristics of
c      each player depending upon the platform and
c      the weapons.
c      lpn        - Logical Player Number
c      platfm     - Platform number
c      gpside(i)  - indicates side of the player
c               B - Blue or friendly side
c               O - Opposing force or enemy side
```

```
c              T,L,A - administrative, no effect on
c                          the battle
c      gpnum(i,4) - Operational Lethality Index OLI,
c                      from Trevor DuPuy's work with
c                      the QJM model.
c      speed       - speed of platform, not used in
c                      this program
c      gpnum(i,5) - Range factor(as proposed by
c                      Trevor DuPuy)
c              = 1 + sqrt(range (KM)) of the most
c                   important wpn on that platform
c
 105  read(7,*,end=99)lpn,platfm,gpside(i),
     +gpnum(i,4),speed,gpnum(i,5)
c
c     Try to match row from battle.dat with gplt
c     using lpn's
c
      if(lpn.ne.gpnum(i,1))goto 105
c
c     If lpn matches but is not friendly, or has
c     no OLI associated with it, try another
c     record
c
      if(gpside(i).ne.'B'.OR.gpnum(i,4).eq.0.0)
     +goto 99
```

```
c
c     Calculate the area affected by the player
c     using the range factor, and also calculate
c     the actual range in meters. Using the OLI,
c     the range, and the grid size (idelta)
c     one can compute how much of the OLI from
c     that player falls into a grid that is
c     idelta X idelta.
c
      toli(nperiod)=toli(nperiod)+gpnum(i,4)
      area=(gpnum(i,5)-1.0)**4*pi
      gpnum(i,6)=((gpnum(i,5)-1.0)**2)*1000.0
      gpnum(i,7)=dble(gpnum(i,4))/
     +((1000000.0/(delta2*2.0)**2)*area)
      if(gptime(I).ne.timex)then
         toli(nperiod)=toli(nperiod)-gpnum(i,4)
         goto 200
      endif
      goto 100
 99   i=i-1
      goto 100
c
c     Statement 200 represents the end of a time
c     period and the beginning of another.
c
 200  ncount(nperiod)=i-1-ict
```

```
      ict=i-1
      timex=gptime(i)
      x=gpnum(i,2)
      y=gpnum(i,3)
      goto 90
c
c     These are the do loops for running through
c     all of the grids in the region as defined
c     by the max-min grids and idelta
c
 250  ncount(nperiod)=i-1-ict
      ibegin=1
      do 2000 iperiod=1,nperiod
         iend=ibegin+ncount(iperiod)-1
c
c     Intialize entropy and entmax which is the
c     maximum entropy possible given the weapons
c     on the battlefields.
c
         entropy=0.00d+00
         entmax=0.00d+00
         i=0
         lyini=int(ymin)-500
         lyend=int(ymax)+500
         lxini=int(xmin)-500
         lxend=int(xmax)+500
```

```
      do 300 xleft=lxini,lxend,idelta
do 400 ylow=lyini,lyend,idelta
c
c     centery and centerx are used to determine
c     which assets have an effect on that grid by
c     locating the center of the grid.
c
                  centerx=float(xleft)+delta2
                  centery=float(ylow)+delta2
                  gridden=0.0
c
c     xleft and ylow are the lower left hand
c     corner of the grid being checked. gridden
c     sums up the friendly density that ranges the
c     center of that grid.
c
            do 500 ii=ibegin,iend
c
c     Classic distance calculation from the center
c     of the grid to the asset.
c
               dist=sqrt((centerx-gpnum(ii,2))**2 +
     +         (centery-gpnum(ii,3))**2)
c
c     Either add the density from this asset if it
c     ranges the grid or test another asset.
```

```
c
                if(dist.le.gpnum(ii,6))
     +gridden=gridden+gpnum(ii,7)
 500        continue
            p=gridden/toli(iperiod)
c
c     If p is zero then gridden was zero so nothing
c     would be added to entropy for the grid and
c     log(0) is difficult to calculate!
c
            if(p.eq.0.0)goto 400
            entropy=entropy+p*(-1.0)*log10(p)
 400     continue
 300  continue
      rgmax=3000.0
c
c     The constant rgmax was chosen as 3000meters
c     because we needed something to give us a
c     more realistic minimum entropy than zero.
c     3000 meters is about the range of an M1A1
c     Abrams main battle tank. If all of the
c     friendly forces assets could be focused into
c     one main battle tank's area of effectiveness,
c     that would be considered the most control
c     possible evidenced by the most concentration
c     of into the smallest area.  It should be
```

```
c     agreed that such a concentration (control)
c     would be totally unrealistic and unreachable,
c     but it gives us an unreachable level of control
c     that can be used for normalization.  It also
c     is very simple and generalizable as long as
c     there are main battel tanks in the battle it
c     should apply.
c
      do 600 jk=ibegin,iend
c
c     entmax is the maximum entropy possible (ie no
c     control or organization is evident).  The
c     maximum entropy would be given by a calculation
c     of entropy with no overlapping ranges.  In other
c     words, there is no grid that contains densities
c     from 2 or more assets.  This yields the smallest
c     maximum entropy  which gives us the most
c     sensitive normalization method.  (the supremum)
c
        entmax=entmax+(gpnum(jk,4)/toli(iperiod))*
     +  (-1.0)*log10(gpnum(jk,7)/toli(iperiod))
 600  continue
      ibegin=iend+1
      p=((delta2*2.0)**2)/(rgmax**2*pi)
      entmin=-log10(p)
      score=(entmax-entropy)/(entmax-entmin)
```

```
      write(8,65)entmin,entropy,entmax,score
65    format(1x,d12.4,3x,d12.4,3x,d12.4,3x,d12.4)
      scor=scor+score/float(nperiod)
2000 continue
      write(8,69)scor,idelta
69    format('The average Spatial Score is ',f8.2,
     +'with grid size=',i6)
3000 end
```

The second part of control is temporal control and is addressed in a program called "tc.f" with output sent to "tc.dat".

```
      Program Temporal_Control_Analysis
c
c     This program will calculate the temporal
c     control indicator for each idelta by idelta
c     grid square and then aggregate the
c     calculations to obtain an overall measure.
c     First, the grids that will be examined will
c     be determined by looking at the min and max
c     X and Y coords for the time period.  Then a
c     margin will be added to both ends
c     to define the entire region of conern.
c
      real speed,gpnum(35000,7),centerx,centery
      real x,y,xmin,ymin,xmax,ymax,lpn,delta2
      double precision max,maxent,gridden(100),
     +totdens,entropy,score,p,pi,area
      integer ylow,xleft,ibegin(100)
      integer platfm,idelta,ncount(100),t
      character*20 timex,gptime(35000)
      character*1 gpside(35000)
      open(unit=6,file='data/gplt.ntc',
     +status='old')
      open(unit=7,file='data/battle.dat',
```

```
      +status='old')
       open(unit=8,file='tc.dat',
      +status='unknown')
c
c      istart indicates where the 'action' of the
c      battle begins. Too many time periods with no
c      action will unfairly lower the temporal
c      control score.  After looking at the data,
c      there appears to be no contact for at least
c      'istart' time periods which equates to 5 *
c      istart minutes
c
c      The size of the grid squares (idelta), the
c      final score (score), the record counter (i),
c      a utility counter (ict), and the time period
c      counter which is the number of 5 minute time
c      periods in the battle, (nperiod).
c
       idelta=100
       delta2=float(idelta)/2.0
       istart=21
       i=0
       pi=4.0d+00*datan(1.0d+00)
       max=0.00d+00
       ent=0.0d+00
       nperiod=0
```

```
      total=0.0
      ict=0
      write(8,1)
 1    format('Min Entropy    Act Entropy    Max
     +Entropy ')
c
c     Find the first time (timex) and then close
c     the file (gplt.ntc) again.  This time is
c     used as a time period separator or sorter.
c
      read(6,10)timex,lpn,x,y
 10   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
      close(unit=6)
      open(unit=6,file='data/gplt.ntc',
     +status='old')
c
c     The first loop atarts with 90.  The period
c     counter is incremented and the min and max
c     grid coordinates are initialized with the
c     x and y coordinates of the first record.
c     These man and max coords are dimensioned
c     so that they can be used as search
c     limiters when setting up the do loops for
c     aggregating the combat power in each grid.
c
      xmax=x
```

```
      xmin=x
      ymax=y
      ymin=y
 90   nperiod=nperiod+1
      ibegin(nperiod)=i
c
c     Intialize entropy and entmax which is the
c     maximum entropy possible given the weapons
c     on the battlefields.
c
      entropy=0.00d+00
      entmax=0.00d+00
 100  close(unit=7)
      open(unit=7,file='data/battle.dat',
     +status='old')
c
c     The i counter is incremented and the
c     gplt.ntc file is read.
c     gptime(i) - time of reading
c     gpnum(i,1)- Logicial Player Number (LPN)
c     gpnum(i,2)- the x coordinate of the player
c     gpnum(i,3)- the y coordinate of the player
c
      i=i+1
      read(6,10,end=250)gptime(i),gpnum(i,1),
     +gpnum(i,2),gpnum(i,3)
```

```
c
c     Establish the boundaries of the region
c     being evaluated
c
      if(gpnum(i,2).lt.xmin)xmin=gpnum(i,2)
      if(gpnum(i,2).gt.xmax)xmax=gpnum(i,2)
      if(gpnum(i,3).lt.ymin)ymin=gpnum(i,3)
      if(gpnum(i,3).gt.ymax)ymax=gpnum(i,3)
c
c     Read in the info from battle.dat-locally
c     produced file showing characteristics of
c     each player depending upon the platform
c     and the weapons.
c     lpn         - Logical Player Number
c     platfm      - Platform number
c     gpside(i)   - indicates side of the player
c             B   - Blue or friendly side
c             O   - Opposing force or enemy side
c             T,L,A - administrative, no effect
c                     on the battle
c     gpnum(i,4) - Operational Lethality Index
c                     (OLI), from
c             Trevor DuPuy's work with the QJM
c              model.
c     speed       - speed of platform, not used
c                    in this program
```

```
c     gpnum(i,5) - Range factor(as proposed by
c                  Trevor DuPuy
c              = 1 + sqrt(range (KM)) of the most
c                  important wpn on that platform
c
c
 105  read(7,*,end=99)lpn,platfm,gpside(i),
     +gpnum(i,4),speed,gpnum(i,5)
c
c     Try to match row from battle.dat with gplt
c     using lpn's
c
      if(lpn.ne.gpnum(i,1))goto 105
c
c     If lpn matches but is not friendly, or has
c     no OLI associated with it, try another record
c
      if(gpside(i).ne.'B'.OR.gpnum(i,4).eq.0.0)
     +goto 99
c
c     Calculate the area affected by the player
c     using the range factor, and also calculate the
c     actual range in meters.  Using the OLI, the
c     range, and the grid size (idelta) one can
c     compute how much of the OLI from that player
c     falls into a grid that is idelta X idelta.
```

```
c
      area=(dble(gpnum(i,5))-1.0d+00)**4*pi
      gpnum(i,6)=((gpnum(i,5)-1.0)**2)*1000.0
      gpnum(i,7)=dble(gpnum(i,4))/((1000000.0/
     +(delta2*2.0)**2)*area)
      if(gptime(I).ne.timex)goto 200
      goto 100
 99   i=i-1
      goto 100
c
c     Statement 200 represents the end of a time
c     period and the beginning of another.
c
c
 200  ncount(nperiod)=i-ibegin(nperiod)
      timex=gptime(i)
      x=gpnum(i,2)
      y=gpnum(i,3)
      goto 90
c
c     These are the do loops for running through
c     all of the grids in the region as defined
c     by the max-min grids and idelta
c
 250  ncount(nperiod)=i-ibegin(nperiod)+1
c
```

```
c       maxent is the maximum entropy that is
c       possible.  This is determined by assuming
c       the maximum entropy condition would be
c       where the entire OLI of the force is equally
c       shared by every segment. Therefore, the 'p'
c       of the  segment would be {1/(#of segments)}
c       * OLI(all segments with the common grid) as
c       the numerator and the total OLI(all segments
c       of the common grid) as the denominator which
c       results in a 'p' of 1/(# of segments)
c       Since the number of segments depends only
c       upon the segments used for calculating the
c       temporal control, 'istart' must be
c       subtracted from the total number of periods
c       in the database.
c
        maxent=-log10(1.0d+00/dble(float
       +(nperiod-istart+1)))
           lyini=int(ymin)-500
           lyend=int(ymax)+500
           lxini=int(xmin)-500
           lxend=int(xmax)+500
           do 300 xleft=lxini,lxend,idelta
do 400 ylow=lyini,lyend,idelta
c
c       centery and centerx are used to determine
```

```
c     which assets have an effect on that grid.
c
                   centerx=float(xleft)+delta2
                   centery=float(ylow)+delta2
c
c     xleft and ylow are the lower left hand
c     corner of the grid being checked.
c
c     gridden sums up the friendly density that
c     range the center of that grid.
c
         totdens=0.0
         do 450 t=istart,nperiod
            gridden(t)=0.0
            iend=ibegin(t)+ncount(t)-1
            do 500 ii=ibegin(t),iend
c
c     Classic distance calculation from the center
c     of the grid to the asset.
c
              dist=sqrt((centerx-gpnum(ii,2))**2 +
     +(centery-gpnum(ii,3))**2)
c
c     Either add the density from this asset if it
c     ranges the grid or test another asset.
c
```

```
               if(dist.le.gpnum(ii,6))then
                gridden(t)=gridden(t)+gpnum(ii,7)
                  endif
 500           continue
c
c     Add up the total density (OLI) for this grid
c     during all of the time periods so that we can
c     use this to determine 'p' for the entropy
c     calculations.
c
               totdens=totdens+gridden(t)
               if(gridden(t).eq.0.0)goto 450
 450        continue
            entropy=0.0
            if(totdens.eq.0.0)goto 400
c
c     Entropy calculation
c
            do 550 it=istart,nperiod
               p=gridden(it)/totdens
c
c     This if statement just helps the
c     calculation by assigning 1 to p instead of
c     zero since the product of p*log10(p) still
c     is zero.
c
```

```
          if(p.eq.0.0)p=1.0
          entropy=entropy+p*(-1.0d+00)*log10(p)
 550      continue
   max=max+totdens*maxent
          ent=ent+totdens*entropy
 400    continue
        write(8,401)max,ent
 401    format('0',8x,d12.4,3x,d12.4)
 300  continue
c
c     Entropy/Max Entropy gives a relative score.
c     The closer to the max, the less temporal
c     control is evident.  The closer entropy is
c     to 0, the more temporal control is evident.
c     Entropy could only be zero if, in every grid,
c     all of the density was condensed into one
c     time period with no other evidence of combat
c     power density in any other time period for
c     that grid.
c
c     1 - the ratio gives the proper perspective on
c     the score so that
c     0 -  means entropy=maxentropy which means
c     little control and 1 means
c     entropy =0 which is all but impossible but
c     serves as the normalization for the least
```

```
c     amount of entropy.
c
      score=1.00000-(ent/max)
      write(8,69)score,idelta
 69   format('Weighted avg temp score is ',d15.8,
     +'Grid Size is ',i6)
      end
```

Doctrinal Positioning Doctrinal positioning is a measure that is indicated by two measurables, Combat Power Projection and Vulnerability. A program in FORTRAN was written for each of these. They are very similar in structure because they represent a symmetric relationship between the positioning of a force and the opposing force. The vulnerability score for a friendly force is exactly the same as the combat power projection score for the opposing force. However, the two scores for the same side are usually not the same and indicate two different concepts. The first program was written for the concept of Combat Power Projection. It is named "cpp.f" and its output is found in "cpp.dat".

```
      Program Combat_Power_Projection_Analysis
c
c     This program will calculate the combat power
c     projection for each time period and then
c     average the calculations to get a measure.
c     First, the grid that will be examined will
c     be determined by looking at the min and max
c     X and Y coords for the time period.  Then a
c     margin will be added to both ends to define
c     the entire region of conern.
c
      real x,y,xmin,ymin,xmax,ymax,lpn
      integer ylow,xleft,iperiod,nperiod
      integer platfm,idelta,ncount(100),nofight
      double precision product,gridoli,gridden,
```

```
     +oli(100),cpp,densmax,score
      real speed,gpnum(35000,7),centerx,centery,
     + xmax(100),ymax(100),ymin(100),xmin(100)
      character*20 timex,gptime(35000),gpside(35000)
      open(unit=6,file='data/gplt.ntc',status='old')
      open(unit=7,file='data/battle.dat',
     +status='old')
      open(unit=8,file='cpp.dat',status='unknown')
c
c     Initialize the maximum density (densmax)
c     counter, the size of the grid squares (idelta),
c     the final score (score), the record counter (i),
c     a utility counter (ict), and the time period
c     counter which is the number of 5 minute time
c     periods in the battle, (nperiod).
c
      idelta=2000
      delta2=float(idelta/2.00)
      score=0
      i=0
      ict=0
      nperiod=0
      pi=4.0*atan(1.0)
c
c     Find the first time (timex) and then close the
c     file (gplt.ntc) again.  This time is used as a
```

```
c     time period separator or sorter.
c
      read(6,10)timex,lpn,x,y
 10   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
      close(unit=6)
      open(unit=6,file='data/gplt.ntc',status='old')
c
c     The first loop starts with 90.  The period
c     counter is incremented and the min and max grid
c     coordinates are initialized with the x and y
c     coordinates of the first record.  These min and
c     max coords are dimensioned so that they can be
c     used as search limiters when setting up the do
c     loops for aggregating the combat power in each
c     grid.
c
 90   nperiod=nperiod+1
      xmax(nperiod)=x
      xmin(nperiod)=x
      ymax(nperiod)=y
      ymin(nperiod)=y
c
c     oli(nperiod) is the total enemy OLI on the
c     battlefield, for that time period.
c
      oli(nperiod)=0.0
```

```
 100  close(unit=7)
      open(unit=7,file='data/battle.dat',
     +status='old')
      i=i+1
c
c     The i counter is incremented and the gplt.ntc
c     file is read.
c     gptime(i) - time of reading
c     gpnum(i,1)- Logicial Player Number (LPN)
c     gpnum(i,2)- the x coordinate of the player
c     gpnum(i,3)- the y coordinate of the player
c
      read(6,10,end=250)gptime(I),gpnum(I,1),
     +gpnum(I,2),gpnum(I,3)
c
c     Adjust the boundaries of the region if
c     necessary
c
      if(gpnum(I,2).lt.xmin(nperiod))xmin(nperiod)=
     +gpnum(I,2)
      if(gpnum(I,2).gt.xmax(nperiod))xmax(nperiod)=
     +gpnum(I,2)
      if(gpnum(I,3).lt.ymin(nperiod))ymin(nperiod)=
     +gpnum(I,3)
      if(gpnum(I,3).gt.ymax(nperiod))ymax(nperiod)=
     +gpnum(I,3)
```

```
c
c     Read in the info from battle.dat-locally
c     produced file showing characteristics of each
c     player depending upon the platform and the
c     weapons.
c     lpn          - Logical Player Number
c     platfm       - Platform number
c     gpside(i)   - indicates the side of the player
c             B   - Blue or friendly side
c             O   - Opposing force or enemy side
c             T,L,A - administrative, no effect on
c                     the battle
c     gpnum(i,4) - Operational Lethality Index OLI,
c                  from Trevor DuPuy's work with the
c                  QJM model.
c     speed        - speed of platform, not used in
c                  this program
c     gpnum(i,5) - Range factor(as proposed by
c                  Trevor DuPuy
c             = 1 + sqrt(range (KM)) of the most
c               important wpn on that platform
c
 105  read(7,*,end=99)lpn,platfm,gpside(i),
     +gpnum(i,4),speed,gpnum(i,5)
c
c     Try to match row from battle.dat with gplt
```

```
c     using lpn's
c
      if(lpn.ne.gpnum(i,1))goto 105
c
c     If lpn matches but is neither friendly or
c     enemy, try another record
c
      if(gpside(i).ne.'B'.AND.gpside(i).ne.'O')
     +goto 99
c
c     If the OLI is zero, it won't help us in
c     this program so go back to gplt.ntc and get
c     another LPN
c
      if(gpnum(i,4).eq.0.0)goto 99
c
c     Calculate the area affected by the player
c     using the range factor, and also calculate
c     the actual range in meters.  Using the OLI,
c     the range, and the grid size (idelta) one
c     can compute how much of the OLI from that
c     player falls into a grid that is idelta X
c     idelta.
c
      area=(gpnum(i,5)-1.0)**4*pi
      gpnum(i,6)=((gpnum(i,5)-1.0)**2)*1000.0
```

```
      gpnum(i,7)=gpnum(i,4)/((1000000.0/float
     +(idelta**2))*area)
c
c     If the player is enemy, add up its OLI for
c     this time period. Also check for the time.
c     If it has changed, we must increment nperiod,
c     reinitialize some counters (like oli) reopen
c     battle.dat, and go through the loop again.
c
      if(gpside(i).eq.'O')oli(nperiod)=oli(nperiod)
     ++dble(gpnum(i,4))
      if(gptime(i).ne.timex)goto 200
c
c     If the time is the same, get another LPN
c     from gplt.ntc.
c
      goto 100
c
c     Statement 99 is used if gplt.ntc gave us an
c     LPN that we don't want in our temporary
c     database.  We go back to gplt.ntc and set the
c     counter back 1.
c
 99   i=i-1
      goto 100
c
```

```
c     Here we set the number of records in the past
c     time period, Reestablish a starting point for
c     the max and min grid calculations, and reset
c     the current time to the next time period
c     (5minutes later).
c
 200  ncount(nperiod)=i-1-ict
      ict=i-1
      x=(xmax(nperiod)+xmin(nperiod))/2.0
      y=(ymax(nperiod)+ymin(nperiod))/2.0
      timex=gptime(i)
      goto 90
 250  ncount(nperiod)=i-1-ict
c
c     These are the do loops for running through all
c     of the grids in the region as defined by the
c     max-min grids and idelta. There is a 5000 meter
c     buffer added to both ends of the x and y limits
c     This is probably overkill and could be dropped
c     if space is critical.
c
      nofight=0
c
c     See the discussion at the end of the program on
c     'nofight'
c
```

```
      ibegin=1
      do 2000 iperiod=1,nperiod
         densmax=0.0
         iend=ibegin+ncount(iperiod)-1
         if(product.eq.0.00d+00)nofight=nofight+1
         product=0.0d+00
         lyini=int(ymin(iperiod))-500
         lyend=int(ymax(iperiod))+500
         lxini=int(xmin(iperiod))-500
         lxend=int(xmax(iperiod))+500
         do 300 xleft=lxini,lxend,idelta
do 400 ylow=lyini,lyend,idelta
c
c     xleft and ylow are the lower left hand corner
c     of the grid being checked for either OLI or
c     being in range of density
c
c
c     gridoli sums up the enemy oli in that grid in
c     one time pass gridden sums up the friendly
c     density that range the center of that grid.
c
           gridoli=0.0d+00
                  gridden=0.0d+00
c
c     The approximation used is: if the circle
```

```
c     defined by the location of the friendly asset
c     and its range includes the center of the grid
c     under consideration, is is assumed that the
c     entire grid is covered and one grid's worth of
c     density is assigned to it.  If the center is
c     not included, it is assumed there is no
c     coverage of the grid by that friendly asset.
c
c     The center points, centerx and centery are
c     calculated based upon the idelta size and the
c     location of the lower left hand corner of
c     the grid (xleft, ylow)
c
            centerx=float(xleft)+delta2
            centery=float(ylow)+delta2
c
            do 500 ii=ibegin,iend
                if(gpside(ii).ne.'B')goto 500
c
c     Classic distance formula - sqrt[(x-x0)^2 +
c     (y-y0)^2]
c
c
                   dist=sqrt((centerx-gpnum(ii,2))
     +**2 + (centery-gpnum(ii,3))**2)
c
```

```
c     If dist is within range then add the density
c     (gpnum(ii,7) to the density sum (gridden)
c
                        if(dist.gt.gpnum(ii,6))goto 500
                        gridden=gridden+gpnum(ii,7)
 500              continue
c
c     If the density of the grid is zero, it doesn't
c     matter what enemy power is contained in that grid,
c     it is not vulnerable to the friendly assets' power.
c     If there IS some density, then continue on to total
c     up the amount of enemy combat power(OLI) is present.
c
                  if(gridden.le.0.0001)goto 400
                  do 520 jj=ibegin,iend
                     if(gpside(jj).ne.'O')goto 520
c
c     As we run through the entire list of players again,
c     if the player is NOT 'O' (enemy) it is ignored.  If
c     it IS enemy, its location is checked by comparing
c     its x and y distance from the center of the grid in
c     question.  If both distances are less than 1/2 of
c     idelta, then the OLI associated with it is included.
c
                     if(abs(gpnum(jj,2)-centerx).gt.
     +delta2)goto 520
```

```
                    if(abs(gpnum(jj,3)-centery).gt.
     +delta2)goto 520
                         gridoli=gridoli+gpnum(jj,4)
 520                continue
c
c     The maximum density is used at the end to normalize
c     the total of the products (OLI * density).  Here is
c     the check to make sure densmax remains the maximum
c     density.  The product is also incremented by the
c     amount of the newly summed density for this grid.
c
                 if(densmax.le.gridden)densmax=gridden
                 product=product+gridoli*gridden
 400             continue
 300   continue
       ibegin=iend+1
c
c     Now that all of the grids have been checked
c     (approximately 4 million of them, depending upon
c     the grid size and the scope of the movement of
c     forces during the battle) the power projection
c     score for the period can be caluclated.  It is:
c            Product/(Max Density * Total Enemy OLI)
c
      write(8,65)densmax,oli(iperiod),product
 65   format(2x,'MAX Dens',d11.3,'OLI ',d11.3,
```

```
     +'ProdSum',d11.3)
      cpp=product/(densmax*oli(iperiod))
      write(8,66)cpp
 66   format(1x,'The final CPP score is ',d13.4)
c
c     This statement adds up the scores for each
c     time period and then presents the average score
c     for the entire battle after the final time
c     period.
c
      score=score+cpp
 2000 continue
      score=score/dble(float(nperiod-nofight))
      write(8,67)score
 67   format('The final average CPP score is ',d13.4)
      write(8,68)nperiod,nofight,idelta
 68   format('Out of ',i6,'time periods,',i6,' had
     +no CPP',i6,' is the grid size')
      end
c
c
c     NOTE:   Taking extra grids into account does
c     not affect the final score because only the
c     total enemy OLI and the maximum friendly density
c     are used for normalization. However, time
c     periods in which there is no contact tend to
```

```
c     lower the vulnerability because each score is
c     divided by the total number of periods to get the
c     average score.  This is probably appropriate if
c     the battle has started and one  of the forces
c     successfully extricates itself from the battle
c     and attacks elsewhere.  However, any time periods
c     that are included in the database before the actual
c     battle starts, lower the average CPP score.   For
c     this reason, the time periods, in the beginning
c     of the battle that indicate no vulnerability, will
c     not be included in the final average.  The
c     'nofight' counter will count the number of time
c     periods that should not be included.  (nperiod -
c     nofight) will yield a more reasonable number of
c     time periods to consider.
c
```

The second program for calculating doctrinal positioning focuses on the concept of Vulnerability. It is named "vul.f" and its output is written to a file called "vul.dat". It looks quite similar to "cpp.f" except that the tests for which side the asset is on are switched between friendly and enemy. The comments throughout the program reflect this distinction.

```
      Program Vulnerability_Analysis
c
c     This program will calculate the vulnerability
c     for each time period and then average the
c     calculations to get a measure.  First, the grid
c     that will be examined will be determined by
c     looking at the min and max X and Y coords for
c     the time period.  Then a margin will be added
c     to both ends to define the entire region of
c     conern.
c
      real x,y,xmin,ymin,xmax,ymax,lpn
      integer ylow,xleft,iperiod,nperiod
      integer platfm,idelta,ncount(100),nofight
      double precision product,gridoli,gridden,
     +oli(100),vul,densmax,score
      real speed,gpnum(35000,7),centerx,centery,
     + xmax(100),ymax(100),ymin(100),xmin(100)
      character*20 timex,gptime(35000),
     +gpside(35000)
```

```
      open(unit=6,file='data/gplt.ntc',status=
     +'old')
      open(unit=7,file='data/battle.dat',status=
     +'old')
      open(unit=8,file='vul1.dat',status=
     +'unknown')
c
c     Initialize the maximum density (densmax)
c     counter, the size of the grid squares
c     (idelta), the final score (score), the record
c     counter (i), a utility counter (ict), and the
c     time period counter which is the number of 5
c     minute time periods in the battle, (nperiod).
c
      idelta=2000

      delta2=float(idelta/2.00)
      score=0
      i=0
      ict=0
      nperiod=0
      pi=4.0*atan(1.0)
c
c     Find the first time (timex) and then close the
c     file (gplt.ntc) again.  This time is used as a
c     time period separator or sorter.
```

```
c
      read(6,10)timex,lpn,x,y
 10   format(a20,1x,f6.0,17x,f6.0,7x,f7.0)
      close(unit=6)
      open(unit=6,file='data/gplt.ntc',status='old')
c
c     The first loop starts with 90.  The period
c     counter is incremented and the min and max grid
c     coordinates are initialized with the x and y
c     coordinates of the first record.  These min and
c     max coords are dimensioned so that they can be
c     used as search limiters when setting up the do
c     loops for aggregating the combat power in each
c     grid.
c
 90   nperiod=nperiod+1
      xmax(nperiod)=x
      xmin(nperiod)=x
      ymax(nperiod)=y
      ymin(nperiod)=y
c
c     oli(nperiod) is the total friendly OLI on the
c     battlefield, for that time period.
c
      oli(nperiod)=0.0
 100  close(unit=7)
```

```
      open(unit=7,file='data/battle.dat',status=
     +'old')
      i=i+1
c
c     The i counter is incremented and the gplt.ntc
c     file is read.
c     gptime(i) - time of reading
c     gpnum(i,1)- Logicial Player Number (LPN)
c     gpnum(i,2)- the x coordinate of the player
c     gpnum(i,3)- the y coordinate of the player
c
      read(6,10,end=250)gptime(I),gpnum(I,1),
     +gpnum(I,2),gpnum(I,3)
c
c     Adjust the boundaries of the region if
c     necessary
c
      if(gpnum(I,2).lt.xmin(nperiod))xmin(nperiod)
     +=gpnum(I,2)
      if(gpnum(I,2).gt.xmax(nperiod))xmax(nperiod)
     +=gpnum(I,2)
      if(gpnum(I,3).lt.ymin(nperiod))ymin(nperiod)
     +=gpnum(I,3)
      if(gpnum(I,3).gt.ymax(nperiod))ymax(nperiod)
     +=gpnum(I,3)
c
```

```
c     Read in the info from battle.dat-locally
c     produced file showing characteristics of each
c     player depending upon the platform and the
c     weapons.
c     lpn          - Logical Player Number
c     platfm       - Platform number
c     gpside(i)    - indicates the side of the player
c               B  - Blue or friendly side
c               O  - Opposing force or enemy side
c               T,L,A - administrative, no effect on
c                       the battle
c     gpnum(i,4) - Operational Lethality Index OLI,
c                    from Trevor DuPuy's work with the
c                    QJM model.
c     speed        - speed of platform, not used in
c                    this program
c     gpnum(i,5) - Range factor(as proposed by
c                    Trevor DuPuy
c               = 1 + sqrt(range (KM)) of the most
c                  important wpn on that platform
c
 105  read(7,*,end=99)lpn,platfm,gpside(i),gpnum(i,4),
     +speed,gpnum(i,5)
c
c     Try to match row from battle.dat with gplt using
c     lpns
```

```
c
      if(lpn.ne.gpnum(i,1))goto 105
c
c     If lpn matches but is neither friendly or enemy,
c     try another record
c
      if(gpside(i).ne.'B'.AND.gpside(i).ne.'O')goto 99
c
c     If the OLI is zero, it won't help us in this
c     program so go back to gplt.ntc and get another
c     LPN
c
      if(gpnum(i,4).eq.0.0)goto 99
c
c     Calculate the area affected by the player using
c     the range factor, and also calculate the actual
c     range in meters.  Using the OLI, the range, and
c     the grid size (idelta) one can compute how much
c     of the OLI from that player falls into a grid
c     that is idelta X idelta.
c
      area=(gpnum(i,5)-1.0)**4*pi
      gpnum(i,6)=((gpnum(i,5)-1.0)**2)*1000.0
      gpnum(i,7)=gpnum(i,4)/((1000000.0/float
     +(idelta**2))*area)
c
```

```
c     If the player is friendly, add up its OLI for
c     this time period Also check for the time.  If
c     it has changed, we must increment nperiod,
c     reinitialize some counters (like oli) reopen
c     battle.dat, and go through the loop again.
c
      if(gpside(i).eq.'B')oli(nperiod)=oli(nperiod)+
     +dble(gpnum(i,4))
      if(gptime(i).ne.timex)goto 200
c
c     If the time is the same, get another LPN from
c     gplt.ntc.
c
      goto 100
c
c     Statement 99 is used if gplt.ntc gave us an
c     LPN that we don't want in our temporary
c     database.  We go back to gplt.ntc and set the
c     counter back 1.
c
 99   i=i-1
      goto 100
c
c     Here we set the number of records in the past
c     time period, Reestablish a starting point for
c     the max and min grid calculations, and reset
```

```
c     the current time to the next time period
c     (5minutes later).
c
 200  ncount(nperiod)=i-1-ict
      ict=i-1
      x=(xmax(nperiod)+xmin(nperiod))/2.0
      y=(ymax(nperiod)+ymin(nperiod))/2.0
      timex=gptime(i)
      goto 90
 250  ncount(nperiod)=i-1-ict
c
c     These are the do loops for running through all
c     of the grids in the region as defined by the
c     max-min grids and idelta
c
c     There is a 5000meter buffer added to both ends
c     of the x and y limits This is probably overkill
c     and could be dropped if space is critical.
c
      nofight=0
c
c     See the discussion at the end of the program on
c     'nofight'
c
      ibegin=1
      do 2000 iperiod=1,nperiod
```

```
          densmax=0.0
          iend=ibegin+ncount(iperiod)-1
          if(product.eq.0.00d+00)nofight=nofight+1
          product=0.0d+00
          lyini=int(ymin(iperiod))-500
          lyend=int(ymax(iperiod))+500
          lxini=int(xmin(iperiod))-500
          lxend=int(xmax(iperiod))+500
          do 300 xleft=lxini,lxend,idelta
do 400 ylow=lyini,lyend,idelta
c
c     xleft and ylow are the lower left hand corner
c     of the grid being checked for either OLI or
c     being in range of density
c
c
c     gridoli sums up the friendly oli in that grid
c     in one time pass
c     gridden sums up the enemy density that range
c     the center of that grid.
c
           gridoli=0.0d+00
                   gridden=0.0d+00
c
c     The approximation used is: if the circle defined
c     by the location of the enemy asset and its range
```

```
c     includes the center of the grid under
c     consideration, is is assumed that the entire grid
c     is covered and one grid's worth of density is
c     assigned to it.  If the center is not included,
c     it is assumed there is no coverage of the grid by
c     that enemy asset.
c
c     The center points, centerx and centery are
c     calculated based upon the idelta size and the
c     location of the lower left hand corner of the grid
c     (xleft, ylow)
c
            centerx=float(xleft)+delta2
            centery=float(ylow)+delta2

            do 500 ii=ibegin,iend
                 if(gpside(ii).ne.'O')goto 500
c
c     Classic distance formula >sqrt[(x-x0)^2+(y-y0)^2]
c
                    dist=sqrt((centerx-gpnum(ii,2))
     +**2 + (centery-gpnum(ii,3))**2)
c
c     If dist is within range then add the density
c     (gpnum(ii,7) to the density sum (gridden)
c
```

```
                  if(dist.gt.gpnum(ii,6))goto 500
                    gridden=gridden+gpnum(ii,7)
500         continue
c
c     If the density of the grid is zero, it doesn't
c     matter what friendly power is contained in that
c     grid, it is not vulnerable to the enemy assets'
c     power.  If there IS some density, then continue on
c     to total up the amount of friendly combat power
c     (OLI) present.
c
            if(gridden.le.0.0001)goto 400
            do 520 jj=ibegin,iend
               if(gpside(jj).ne.'B')goto 520
c
c     As we run through the entire list of players again,
c     if the player is NOT 'B' (friendly) it is ignored.
c     If it is friendly, its location is checked by
c     comparing its x and y distance from the center of
c     the grid in question.  If both distances are less
c     than 1/2 of idelta, then the OLI associated with it
c     is included.
c
             if(abs(gpnum(jj,2)-centerx).gt.delta2)
     +goto 520
             if(abs(gpnum(jj,3)-centery).gt.delta2)
```

```
     +goto 520
                        gridoli=gridoli+gpnum(jj,4)
 520            continue
c
c     The maximum density is used at the end to normalize
c     the total of the products (OLI * density).  Here is
c     the check to make sure densmax remains the maximum
c     density.  The product is also incremented by the
c     amount of the newly summed density for this grid.
c
               if(densmax.le.gridden)densmax=gridden
               product=product+gridoli*gridden
 400           continue
 300    continue
        ibegin=iend+1
c
c     Now that all of the grids have been checked
c     (approximately 4 million of them, depending upon
c     the grid size and the scope of the movement of
c     forces during the battle) the power projection
c     score for the period can be caluclated.  It is:
c             Product/(Max Density * Total Friendly OLI)
c
      write(8,65)densmax,oli(iperiod),product
 65   format(2x,'MAX Dens',d11.3,'OLI ',d11.3,'ProdSum',
     +d11.3)
```

```
      vul=product/(densmax*oli(iperiod))
      write(8,66)vul
 66   format(1x,'The final Vulnerability score is ',
     +d13.4)
c
c     This statement adds up the scores for each time
c     period and then presents the average score for the
c     entire battle after the final time period.
c
      score=score+vul
 2000 continue
      score=score/dble(float(nperiod-nofight))
      write(8,67)score
 67   format('The final average Vulnerability score is
     +1.0 - ',d13.4)
      write(8,68)nperiod,nofight
 68   format('Out of ',i6,'time periods,',i6,' had no
     +vulnerability')
      write(8,70)idelta
 70   format('The grid size was ',i6)
      end
c
c
c     NOTE:   Taking extra grids into account does not
c     affect the final score because only the total
c     friendly OLI and the maximum enemy density are
```

```
c     used for normalization.  However, time periods in
c     which there is no contact tend to lower the
c     vulnerability because each score is divided by
c     the total number of periods to get the average
c     score.  This is probably appropriate if the battle
c     has started and the enemy successfully extricates
c     itself from the battle and attacks elsewhere.
c     However, any time periods that are included in the
c     database before the actual battle starts, lower
c     the average vulnerability and rasie the
c     vulnerability score.  For this reason, the time
c     periods, in the beginning of the battle that
c     indicate no vulnerability, will not be included in
c     the final average.  The 'nofight' counter will
c     count the number of time periods that should not be
c     included.  (nperiod - nofight) will yield a more
c     reasonable number of time periods to consider.
c
```

C.2 Data Conversion and Production

The data used for the above programs had to be gathered and structured. Much of the data came from the database files stored at the ARI-POM (Army Research Insitute - Presidio of Monterey) and obtained from the instrumented training grounds in the National Training Center, Fort Irwin. California. The files required by the FORTRAN programs had to be ASCII files so the database files were transformed into comma delimited files by using the ORACLE database and by Microsoft EXCEL. INGRESS or other database managers could also be used. Care should be taken that files exactly like the ones produced are the only files that will be successfully read by the FORTRAN programs.

Data Conversion Programs The file "platform.dat" carries to the FORTRAN programs all of the key data from the spreadsheet just described. We produced the rest of the data needed in the programs by running other FORTRAN data coversion programs that used "platform.dat" and other key NTC data as input.

All of the FORTRAN programs are listed below and are explained in the documentation contained within the program. The program is called "makedat.f" and produces files called "battle.dat", "wpnct.dat", and "volume.dat". These files, along with "platform.dat", provide all of the data required as input for the FORTRAN programs that calculate the measurables.

```
      PROGRAM MAKE_BATTLE_DATA

C
```

```
C     THIS PROGRAM WILL MATCH UP THE LPN WITH THE
c     PLATFORM # THEN, THE PLATFORM # WILL BE USED TO
c     IDENTIFY THE OLI AND ASSOCIATED WITH IT.
C     FINALLY, A TABLE 'BATTLE.DAT' WILL BE
C     CONSTRUCTED THAT WILL HAVE THE LPN, OLI, AND
C     SPEED FOR THE BATTLE.
C
      REAL SPEED,AMMO,OLI,RANGE
      INTEGER LPN,PN,PLATFM,WPN(100),W1,W2,W3
      CHARACTER*11 STATUS
      CHARACTER*1 SIDE
      OPEN(UNIT=6,FILE='data/esit.ntc',STATUS='old')
      OPEN(UNIT=8,FILE='data/battle.dat',
     +STATUS='unknown')
C
C     READ IN THE PLATFORM, LPN INFO
C
 1    READ(6,80,END=20)LPN,STATUS,SIDE,PLATFM
 80   FORMAT(I6,102X,A11,5X,A1,54X,I6)
      IF(STATUS.NE.'Operational')GOTO 1
      IF(SIDE.EQ.'B'.OR.SIDE.EQ.'O')GOTO 2
      GOTO 1
 2    OPEN(UNIT=7,FILE='data/platform.dat',
     +STATUS='OLD')
 3    READ(7,*,END=4)PN,SPEED,AMMO,OLI,RANGE
 5    IF(PN.EQ.PLATFM)THEN
```

```
        WRITE(8,81)LPN,PLATFM,SIDE,OLI,SPEED,RANGE
 81     FORMAT(I6,I6,2X,A1,2X,f8.2,f8.2,2X,F6.2)
        CLOSE(UNIT=7)
        GOTO 1
        ENDIF
      GOTO 3
 4    WRITE(8,82)LPN,PLATFM
 82   FORMAT(I6,I6,2x,'T',2x,'00000.00','00000.00',
     +2x,'000.00',
     +'THERE IS NO MATCH')
      CLOSE(UNIT=7)
      GOTO 1
 20   CLOSE(UNIT=7)
      close(unit=8)


C ************************************************
C
C     THIS PART OF THE PROGRAM WILL ADD UP THE NUMBER
C     OF ROUNDS FIRED BY EACH TYPE OF WEAPON DURING
C     THE BATTLE.
C
      OPEN(UNIT=9,FILE='data/fet.ntc',STATUS='old')
      OPEN(UNIT=10,FILE='data/volume.dat',
     +STATUS='unknown')
C
```

```
C     INITIALIZE ALL COUNTS AT ZERO
C
      DO 50 I=1,85
         WPN(I)=0
 50      CONTINUE
  9   READ(9,51,end=21) SIDE,W1
 51   FORMAT(37X,a1,32X,I3)
      IF(SIDE.NE.'B')GOTO 9
      WPN(W1)=WPN(W1)+1
      GOTO 9
 21   DO 100 J=1,85
      WRITE(10,12)J,WPN(J)
 12   FORMAT(4X,I2,5X,I4)
 100  CONTINUE
 22   close(unit=9)
c
c
C****************************************************
C This program requires the use of the files esit.ntc
C and fet.ntc which are ascii files produced by
C ORACLE by converting dbase files that are available
C from ARIPOM from the ntc database. Also required is
C a file called 'platform.dat' which is a file
C produced by the author of this program but extracted
C from an EXCEL spreadsheet.  It contains operational
C lethality index (OLI) numbers for each platform
```

```
C contained in the NTC database. Also included in
C platform.dat are the columns of speed, range
C factors (not the range).
C
C battle.dat is produced which contains a large part
C of what will be used for many of the fortran
C programs.  Also produced is a small file called
C volume.dat which contains the volume of each type
C of weapon that was fired during the entire battle in
C question.
C
C volume.dat is used by the weapons usage measure and
C the combined arms measure.
C
C****************************************************
c
c This part of the program calls on the file 'esit.ntc'
C which is the initialization file for all ntc battles.
C It contains the status and, side, weapon and platform
C type of weapons that will actually be used in this
C particular battle.The output will be the file
C wpnct.dat which contains the number of each type of
C wpn for the friendly side.  This file will be used
C for calculating the weapons usage and combained arms
c measures and specifically in the ada.f, carm.f
C programs.
```

```
c
c*****************************************************
c
c        PROGRAM COUNT_WPNS
C
      close(unit=6)
      OPEN(UNIT=6,FILE='data/esit.ntc',STATUS='old')
      OPEN(UNIT=11,FILE='data/wpnct.dat',
     +STATUS='unknown')
C
C
C     INITIALIZE ALL WPN COUNTS AT ZERO
C
      DO 150 I=1,85
         WPN(I)=0
 150  CONTINUE
 109   READ(6,180,end=120) status,side,w1,w2,w3
 180   FORMAT(108X,A11,5X,A1,15X,I3,11X,I3,11X,I3)
      IF(SIDE.NE.'B')GOTO 109
      IF(STATUS.NE.'Operational')GOTO 109
 115   WPN(W1)=WPN(W1)+1
      WPN(W2)=WPN(W2)+1
      WPN(W3)=WPN(W3)+1
      GOTO 109
 120  DO 1100 J=1,85
      WRITE(11,112)J,WPN(J)
```

```
1100 CONTINUE
112  FORMAT(4X,I2,7X,I4)
     END
```

Appendix D

Packet Given to Participants

Mission Briefing for Evaluators

Thank you for participating in this research effort. We are interested in your views of how certain battles were conducted. You have experience in the Army and with evaluating tactics and small unit operations, that is why you were selected.

First you will be asked to read some instructions and clarifying comments about the terminology used during the evaluations. Please read the instructions and comments carefully. If you are confused at all, your evaluations may not be valid.

Instructions

- You will be viewing eight selected missions that are replays of battles fought at the National Training Center, Ft. Irwin, CA. Select one of the missions by interpreting the mission number on the evaluation form together with the mission code listing in your folder. n932-m07 should be read as 1993 - rotation 02 - mission number n932-m07.

- Simply click on the appropriate mission. Position the grid on the screen so that the upper right-hand corner of the screen contains the intersection of the two gridlines shown under the position column of the mission code list.

- You may view the battle using either battle replay or battle trace. Other options offered in the software will be explained to you as you proceed.

- Make sure you know the areas that you need to evaluate for each mission. Not all areas should be evaluated for every mission.

- Rate the area from low(1) to high(5). Low does not necessarily mean bad and high does not necessarily mean good. There are only two or three missions rated for each area.

- There is a short 1-page summary of the After-Action-Review that took place immediately after the battle. The information contained in the summary may also be used to form evaluations.

- You may review any of the missions and there is no time limit.

Comments on Evaluation Areas

Cdr's Mental Agility You are to evaluate whether the commander was able to make a quick change of plans during the battle in reaction to an unsuspected enemy action. This is not always obvious, especially without the operations order available.

Unit's Mobility Your opinion of how quickly the unit moved when moving was required. This should be a weighted evaluation. In other words, if most of the unit moved slowly but one small portion moved quickly, a lower score would be appropriate.

Use of Firepower Actual use of the asset. Further explanation follows.

Armor/Infantry How much did the Armor and Infantry units actually fire. You can visually evaluate direct-fire weapons in some battles while in others you must look at the fire event records.

Fire Support How much firepower did the Field Artillery, mortars, and air support actually contribute by calling in missions?

Air Defense Since ADA weapons may only fire if enemy air is present, another measure of actual use of ADA may be necessary. The positioning of ADA assets indicates the level of concern given to the ADA battlefield operating system. Unfortunately, simply checking the AAR for ADA statistics does not relay how often they fired or how well they were positioned. It may just be an indicator of how technically proficient the operators are.

Engineers There is little evidence of engineer use in the offense. Most of the defensive AARs address the use of the engineers in laying minefields and in preparing defensive positions for the crews and vehicles.

Overall Usage In your opinion, how well did the unit use the firepower (including engineers and ADA) available?

Combined Arms In your opinion, how balanced was the battle with respect to use of the different battlefield operating systems just evaluated?

Cbt Pwr Concentration Throughout the battle, were the friendly forces generally concentrated or dispersed? This is not meant to be an evaluation of how well the friendly force used dispersion vs concentration. Nor should it be an indication that you agree or disagree with the level of concentration.

Cbt Pwr Coordination This area refers to the timing of the concentration. Did the commander concentrate his force at one time and disperse them the next or did he leave them concentrated the entire time? In other words, did the level of concentration change drastically (5) throughout the battle or did it remain about the same (1) for the duration?

Defense - Good position against attack Did the friendly force concentrate its forces and combat power against the main enemy effort ? Or, did the main defense (kill zone) miss the main enemy attack? Also, when the main attack was identified, did the friendly force commander bring in other forces to mass against the attack?

Offense - Main effort hit enemy's weak point Was the friendly offensive main effort focused against a vulnerable or weakly defended area (5) or was it a frontal attack against the enemy's strongest position?(5)

Individual Subjective Evaluations of Doctrinal Measures

Rate each area indicated from 1 (low) to 5 (high)

		MSN 2	MSN 3	MSN 5	MSN 10	MSN 12	MSN 13	MSN 18	MSN 20
Doctrinal Concepts									
Organizational Agility			☐	☐					
Cdr's Mental Agility	Reacts With Plan	☐	☐	☐	☐	☐	☐	☐	☐
Unit's Mobility	How much mobility?				☐	☐	☐		
Use of Fire Power									
	Armor/Infantry				☐	☐		☐	
	Fire Support	☐	☐						☐
	Air Defense				☐	☐			☐
	Engineers	☐						☐	
	Overall usage		☐	☐	☐			☐	
Combined Arms	Overall Balance	☐			☐		☐		
Cbt Power Concentration	Throughout Battle		☐	☐					☐
Cbt Power Coordination	Timing		☐				☐		☐
Defense									
Good Position Against Main Attack		☐		☐					
Offense									
Main Effort at Enemy's Weak Point						☐	☐		

Figure D.1: Evaluation form given to the experts.

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